Wheeled Mobility and Seating Equipment Following Spinal Cord Injury

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Key Points

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Wheeled Mobility and Seating Equipment

1.0 Executive Summary

Wheelchairs and seating are one of the most important and most frequently used assistive technologies for people who have a spinal cord injury (World Health Organization, 2008; Bergstrom & Samuelsson 2006; Di Marco et al. 2003). With the development and improvement of materials and manufacturing, the availability and diversity of these products has increased dramatically over the past several decades. This has increased the ability to "fine tune" the wheelchair set up to fit the individual's needs. However, this has also made the process of choosing an appropriate wheelchair more complex (Gagnon et al. 2005) both for the person with SCI and the clinician prescribing the equipment. In this chapter, section 3.0 reviews the research literature related to manual wheelchairs, from the optimal positioning of the upper extremities for propulsion from kinetic and kinematic perspectives, to the effect of different features and options on fit and function. The section also reviews the research about wheelchair use.

There currently is less research related to power wheelchairs, but this does not diminish the importance of power for those people who are unable to propel a manual wheelchair or choose to have both a manual and a power wheelchair for various physical and functional reasons. Section 4.0 reviews the research literature related to the characteristics of power wheelchairs, and driver controls. The larger area of research for power wheelchairs is in the realm of power positioning technology. There are two aspects to power positioning technology; 1) how it is used in daily life and, 2) the impact it has on skin integrity.

Wheelchair seating equipment, particularly cushions, has experienced the same growth in products to support postural, comfort, functional and skin integrity needs. The diversity of equipment now available has also created challenges with finding the optimal seating system; seat cushion, back support, head support, and all other body supports. The acceleration of development related to seat cushions is likely in response to estimates that indicate 50% to 80% of persons with SCI will develop a pressure ulcer (Brienza & Karg 1998) in their lifetime and the costs associated with treating wounds. Section 5.0, Seating equipment for wheelchairs, reviews the research related to cushions and back supports, with the studies often comparing equipment to deteremine optimal pressure management, implications on posture and effects on functional tasks. This section includes a review of interface pressure mapping (IPM) as it is a clinical tool that holds potential to assist the clinician but there are limitations in how it can be used clinically. Researchers also use IPM to compare cushions, research the effect of changing body position and different postural changes on pressure to better understand the implications of sitting pressures on pressure management. There are benefits and limitations with this technology that have implications for application clinically and in evaluating the research using IPM. Because sitting surface pressures and the need for pressure management is critical for most people with spinal cord injury regardless of the type of wheelchair they use, section 6.0 reviews the research related to body position changes, whether through power positioning technology or physically changing body postion.

The final section was added during the previous revision, due to the growth of research exploring wheelchair provision. Obtaining a properly fitting wheelchair has a significant impact on all aspects of a person's life, from comfort and function to affecting secondary complications such as pressure injuries. This section rounds out this chapter on wheelchairs and seating. While there are many aspects of life for a person with a spinal cord injury that overlap with wheelchairs and seating, the focus of this chapter has remained on the equipment itself.

2.0 Introduction to Wheeled Mobility and Seating Equipment

The wheelchair is one of the most important pieces of assistive technology for the individual with a spinal cord injury (SCI) (World Health Organization, 2008; Bergstrom & Samuelsson 2006; Di Marco et al. 2003). The wheelchair and seating equipment must be a source of effective mobility conducted in different environments. Aditionally, it must enable and influence the extent and quality of activity and participation while providing comfort, stability and safety not only when sitting, but also when participating in dynamic activities all the while meeting the individual's needs for function, comfort, postural support and, tone management (World Health Organization, 2008; May et al. 2004).

Wheelchair and seating must also address and prevent secondary complications such as: pressure injuries; progression of negative postural changes, both muscular and skeletal; and pain (upper limb and back) from the mechanical stress of pushing a wheelchair and the gravitational impact on the body when sitting for long periods of time (World Health Organization, 2008; Curtis et al. 1999).

While there is no such thing as a perfect wheelchair or seating system (Garber 1985; Garber & Dyerly 1991) a multitude of variables must be considered to obtain the best fit. Studies support that wheelchair and seating equipment needs should be determined on an individual basis and modified to meet the needs of the user (Hastings et al. 2003; Janssen-Potten et al. 2001). It is suggested that clinicians use objective evaluation, clinical judgment and client input in the prescription and set-up of the equipment (Garber & Dyerly 1991; Garber 1995; May et al. 2004).

There is a growing body of research evidence to augment clinical decision making for wheelchairs and seating equipment (May et al. 2004). While the growth of level 1 and 2 evidence research in the recent years assists to advance this field, it is important to recognize that not all aspects of wheelchairs and seating can be controlled and that level 3, 4 and 5 evidence research continues to be critical for understanding the unique and person-based aspects of this field. This growth of research is exciting and important to the advancement of the field; however, it is resulting in an ever-growing length of this chapter which needs to be managed. For this reason, in sections where there is a mix of levels of evidence, and the level 5 evidence studies do not add novel or compelling evidence, their contribution will be summarized just prior to the discussion section under the subheading of *Summarized Level 5 Evidence Studies*. This assures the reader of all the studies reviewed and acknowledges the important contribution of all studies to the field of wheelchairs and seating. Please note that the contribution from these studies will not be included in the related discussion or conclusions.

The Wheeled Mobility and Seating Equipment chapter is a synthesis of studies that explore various aspects of wheelchairs and seating for individuals with SCI. The chapter has been organized to be as clinically relevant as possible. The studies reviewed in this chapter are organized into subsections: 1) manual wheelchair technology including propulsion, 'set up' or configuration, training and, use; 2) power mobility technology, including power mobility use, driving controls, power positioning devices and alternate power mobility options, 3) seating equipment including the use of pressure mapping, postural implications and impact of seating equipment on function, cushions, and changes in pressure during static sitting and dynamic movement while sitting; 4) alternate forms of mobility, 5) position changes for managing sitting pressure/postural issues, fatigue and discomfort and; 6) wheelchair and seating provision and service delivery process.

3.0 Manual Wheelchairs

The growth of wheelchair related research has been seen most in that of manual wheelchairs. There is a diversity of research which reflects the diversity of factors and variables that affect the fit of manual wheelchair to the person, in particular how it affects propelling the manual wheelchair. The section begins with a review of studies of manual wheelchair propulsion; kinetic and kinematic findings on the upper extreminty and trunk in relation to stroke patterns and propulsion on level and non-level surfaces. It follows with the *Effects of Wheelchair Frame and/or Set-up on Propulsion, Training and Wheelchair Use* respectively.

3.1 Wheelchair Propulsion

People with a spinal cord injury often rely upon manual wheelchair propulsion as their primary means of independent mobility. However, it has been reported that between 25% and 80% of of people who use manual wheelchairs experience wrist, elbow and shoulder injuries often due to overuse and/or poor propulsion ergonomics (Cooper et al. 2001; Boninger et al. 1999). The articles in this section focus on the kinetic (forces, mechanical loads, moments (torque)) and kinematics (movement at joints or between body segments) during propulsion, the effects of propulsion on the body and the effect of the environment on propulsion.

Most articles refer to wheelchair propulsion in two phases, push or propulsion phase and recovery phase. The push phase starts when the hand contacts the hand rim and ends when contact with hand rim ends. The recovery phase is the time period where the hands are not in contact with the hand rim, typically moving to prepare for the next push cycle (Ambrosia et al. 2005; VanLandewijick et al. 1994).

The stroke pattern in wheelchair propulsion subsection is presented first as the pattern types are often referred to in subsequent sections. It is also worth noting that for many studies in this section, data was collected on various surfaces, often in a lab setting. In the lab settings, researchers used stationary treadmills, ergonometers, and/or dynamometers. There is some discussion within several articles related to the pros and cons of using one of these devices over the others. This discussion was felt by the chapter authors to be a research-based issue and was beyond the scope of this clinical-based document therefore the article content related to this specific topic was not reviewed or included in the tables below.

The second and third subsections focus more specifically on kinetics and kinematics. Due to the large volume of research in this area the articles were separated roughly into level surfaces and non-level surfaces. The non-level surfaces include surfaces such as side slopes, uneven surfaces, wheelies, curbs and inclines.

3.1.1 Stroke Pattern in Wheelchair Propulsion

Stroke pattern refers to the trajectory of the hand during the recovery phase of manual wheelchair propulsion. During the propulsive or push phase, the hand follows the path of the handrim. However, during the recovery phase the user can choose any trajectory to prepare for the next push. Four stroke patterns have been identified for users of manual wheelchairs based on the pattern used during the recovery phase (Shimada et al. 1998; Boninger et al. 2002; Koontz et al. 2009):

- Semicircular (SC): the hands fall below the hand rim during recovery phase.
- Single looping over propulsion (SLOP): the hands rise above the hand rim during recovery phase.
- Double looping over propulsion (DLOP): the hands rise above the hand rim, then cross over and drop below the hand rim during the recovery phase.

• Arcing (ARC): The third metacarpophalangeal (MP) follows an arc along the path of the hand rim during the recovery phase.

The following articles examine the stroke patterns as well as the kinetics and kinematics of the different stroke patterns in relation to the potential for upper extremity injury due to suboptimal biomechanics and/or chronic overuse.

Author Year Country Research Design Score	Methods	Outcome
Kwarciak et al. 2012 USA Post-Test N=25	Population: Mean age: 35.7 yr; Gender: males=23, females=2; Level of injury: paraplegia (T3-L1)=17, spinal bifida(T10- L1)=6, tetraplegia(C6-7)=1, spinal lipoma=1; Mean use of w/c:16.9 yr. Intervention: Four propulsion patterns (single loop (SL), arcing (ARC), double loop (DL) and semi-circular (SC)) were compared to the participants' normal pattern. Parameters measured were cadence, peak force, contact angle, braking moment, and impact, as well as EMG muscle activity in specific upper extremity muscles or muscle groups. Data collection was completed for each participant's normal pattern after an acclimation period. Subsequent stroke patterns were randomly assigned with a period of instruction and practice prior to data collection. Each data collection period lasted 60 sec with 30 sec warm up prior and rest times between to avoid fatigue. Outcome Measures: Surface electrodes were used at to measure muscle activation at the shoulder (upper and middle trapezius, pectoralis major, anterior, middle and posterior deltoid), elbow (long head of triceps and biceps), and wrist (wrist extensors and flexors). Data for stroke pattern were collected on the right hand (MCP joint) and wheel (3 points on the hub of wheel). Propulsion variables were measured by an instrumented rear wheel while the participant propelled on a wheelchair treadmill that was normalized to the individual's parameters on low pile carpet as determined at the start of the	 Normal propulsion patterns: DL=15, SL=6, ARC=2, SC=2. Comparisons across patterns were based on average of normal (across low pile carpet and self-selected speed) and experimental propulsion trials. Hand rim biomechanics: DL=smallest cadence, largest contact angle, smallest braking moment compared to ARC pattern (all p<0.05). The latter 2 were also significantly different than the SL pattern (p<0.05). Though not significant, DL had highest peak force value and SC the lowest peak force as well as lowest impact. Contact angle of SC was significantly larger compared to arching pattern (p<0.05). Muscle activity: No significant differences were found in muscle activity between stroke patterns.
Raina et al. 2012b USA Post-Test N=34	Population: Mean age: 74.5 yr; Gender: males=31, females=3; Level of injury: paraplegia=16(T6-L1), tetraplegia=18(C6- 7), all AIS A or B motor complete; Mean height: 1.75 m. Intervention: Participants propelled their own manual w/c on a stationary ergometric normalized to propelling on tile floor for a 30 sec period to achieve steady state	 Velocity of wrist prior to contact was significantly correlated (r=0.74, p<0.05) with the magnitude of impact force for all participants; tetraplegia=0.81±0.24 m/second, 0.062±0.02 N/kg; paraplegia=0.95±0.37 m/second, 0.061±0.03 N/kg.

 Table 1. Stroke Pattern in Wheelchair Propulsion

Author Year Country Research Design Score	Methods		Outcome
Total Sample Size			
Research Design Score Total Sample Size	Methods propulsion followed by 10 sec of data collection for each of four propulsion patterns (arcing (ARC), single–loop-over propulsion (SLOP), semi-circular (SC), double–loop-over propulsion (DLOP)). Outcome Measures: Push pattern analysis included velocity prior to contact, peak impact force, and the effectiveness of the force at impact. Force was measured at the contact point with the hand rim for the period when force was more than 5 N as measured using the Smart Wheel (3 strain force transducers). Propulsion patterns were tracked using a 6-camera system with 16 reflective markers placed on the manubrium, xiphoid process, spinous processes of T3&T10, greater tubercle of the humerus, medial and lateral epicondyles, deltoid tuberosity, mid forearm, radial and ulnar styloids, and head of 3 rd and 5 th metacarpals, three markers on the wheel.	2. 3. 4. 5. 6. 7. 8. 9.	Outcome Correlation between wrist velocity prior to contact and magnitude of impact force normalized to body weight was stronger for participants with paraplegia (r=0.92) than tetraplegia (r=0.45). No significant differences in magnitude of impact force between participants with paraplegia and tetraplegia (p>0.05). Participants with tetraplegia had significantly higher (p=0.02) radial component of impact force than participants with paraplegia (9.2% & 4% respectively). Percent of impact force applied in tangential direction (effective force) was significantly higher (p=0.005) in paraplegia group (94%) than in tetraplegia group (88%) – suggest lower effectiveness of force application at impact for tetraplegia group. ARC, SC and SLOP patterns were preferred by both participant groups. The most common propulsive pattern in the combined sample population was the SLOP. DLOP not used by participants with tetraplegia; the SC pattern was observed in only one participant with paraplegia. Impact force between hand movement
	Population: SCI (n=9); Mean age: 28.9 yr;	10. 11. 12.	patterns was not significantly different between patterns (p>0.05) (force normalized to arm weight to account for between subject body mass differences). Force effectiveness was not significantly different between propulsion patterns. Percent of effective force at contact varied between 0-25% and 25-95% for participants with tetraplegia and paraplegia, respectively. The same pattern showed different percentages of force effectiveness in the two participant groups (paraplegia versus tetraplegia).
Feng et al. 2010 Taiwan Post-Test N=10	Gender: NR; Level of injury: Lumbar=2.2, Thoracic=7.8; Mean time since injury: 11.3 yr; Experience using manual w/c range 2- 18 yr. Intervention: To investigate the glenohumeral kinematic difference between circular and pumping stroke wheelchair propulsion in glenohumeral joint	2.	in the temporal variables between the two stroke techniques (similar time spent in the pushing and recovery movements). Circular and pumping strokes showed a ratio of 4:6 between push and recovery times.

Author Year Country Research Design Score	Methods	Outcome
Total Sample Size		
	(GHJ) excursion related to shoulder impingement (defined as internal or external rotation beyond 30° of forward flexion or 30° of abduction). Participants used a study w/c set up to standardize arm position in an optimal position in relation to wheel. Testing done on a roller system, following a protocol of 5 min warm up and three tests of 10 cycles of propulsion for each propulsion pattern; patterns randomly assigned. Outcome measures : Zebris Motion analysis system with six markers (acromion process, lateral epicondyles, ulnar styloids, and a rigid cross placed on sternum to capture three planes) to measure temporal parameters [push time(s); recovery time (s); push phase (% of cycle); recovery cycle (% of cycle)] and kinematic parameters [Initial and end position flexion- extension, abduction-adduction, and internal-external rotation (degrees)] of each propulsion technique, in addition to impingement excursion.	 In the sagittal plane the starting and ending positions were similar between the two stroke techniques with both starting and ending with approximately 40° of shoulder extension. There were significant differences between stroke patterns in the frontal and transverse planes;1) on average pumping stroke compared to circular started in larger abduction (56.6°+9.5° versus 44.7°+7.4°, p=0.001), and internal rotation (3.6°+10.3° versus- 10.3°+6.7°, p=020). 2). End position for pumping was larger than circular for abduction (57.6°+5.1° versus 45.4°+6.2°. p=0.001) and internal rotation (34.1°+11.8° versus- 13.4°+7.3°, p=0.001). The pumping stroke also had a significantly greater excursion in the sagittal, (71.4°+11.4° versus 55.9°+ 11.8°, p=0.001), frontal, (57.6°+5.1° versus 45.4°+6.2°) and transverse planes (42.4°+11.8° versus 25.7°+7.3°) compared to the circular stroke. A greater percentage of the GHJ movement met impingement excursion (almost three times) during the pumping stroke compared to circular stroke (11.6+11.2% versus
Koontz et al. 2009 USA Post-Test N=29	Population: Mean age: 47.0 yr; Gender: males=28, females=1; Injury etiology: SCI=24 (cervical=5, thoracic=14, lumbar=5), amputation=3, neuropathy=1, spina bifida=1; Length of time using w/c: 14.2 yr. Intervention: Patients propelled their manual wheelchairs on randomly selected test surfaces consisting of linoleum (1.20 m by 4.50 m), high-pile carpet (1.50 m by 4.50m) and a plywood ramp (1.20 m by 3.60 m, 5° grade) for three test trials. Outcome Measures: 2 SMARTWheels and a camera set up to collect data for stroke pattern and propulsion variables of applied force, velocity, distance per stroke, contact angle and moment.	 The single looping (SL) over propulsion pattern was most commonly used for the initiation of motion (44.9%), followed by arc (35.9%), double looping (DL) over propulsion (14.1%) and semicircular (SC) pattern, (5.1%). The number of strokes used and the type of surface had no significant effect on the pattern used. Body weight, body and wheelchair weight combined, and age were not significantly different between patterns Duration of wheelchair use was significantly different between patterns types onlinoleum for the 1st and 2nd strokes. (p=0.036 and p=0.008 respectively) Participants in the DL and SC pattern group had been using wheelchairs longer (stroke 1: DL/SC=28.0±12.5 yr, SL=11.8±9.7 yr, arc=13.7±8.0 yr; stroke 2: DL/SC=22.0±11.5yr, SL=10.3±6.7 yr, arc=10.5±6.7 yr). On linoleum:

Author Year Country		
Research Design	Methods	Outcome
Score Total Sample Size		
		 Between group differences approached significance in regard to contact angle with DL/SC having a larger contact angle at stroke 1 (p=0.069) (DL/SC=56.70±11.10°, SL=45.00±5.55°, arc=31.30±5.1°). Between group differences approached significance in regard to average velocity with DL/SC having a faster average velocity (p=0.075) (DL/SC: 0.92±0.06 m/s, SL=0.75±0.06 m/s, arc=0.73±0.07 m/s) DL/SC covered significantly more distance per stroke at stroke 2 compared to arc (p=0.016) (DL/SC=0.53±0.08 m, arc=0.44±0.10 m). On carpet: Between group differences were significant in regard to peak moment at stroke 3 (p=0.009) (DL/SC=0.26±0.02 m, SL=0.23±0.01 m, arc=0.18±0.02m), average velocity at stroke 3 (DL/SC=1.07±0.08 m/s, SL=0.82±0.06 m/s, arc=0.70±0.09 m/s) and distance per stroke at stroke 3 (p=0.036) (DL/SC=0.53±0.12 m, SL=0.45±0.08 m, arc=0.42±0.13 m). Compared to arc, DL/SC had a significantly greater peak moment (p=0.07), average velocity (p=0.019) and distance per stroke (p=0.043) at stroke 3. On the ramp: Between group differences were significant in regard to peak resultant force at stroke 3 (p=0.049) (DL/SC=1.64±0.20, SL=1.37±0.11, arc=1.07±0.13). Compared to arc, DL/SC had a non- significantly greater peak resultant force at stroke 3 (p=0.066).
Richter et al. 2007a	males=19, females=7; Mean wheelchair use=17 yr; Mean weight: 69.8 kg; Level of injury: paraplegia; Chronicity=chronic. Intervention: Self propulsion in personal	 SLOP; 27% DLOP; 0% SC. 3° slope stroke pattern: 69% ARC; 19% SLOP; 12% DLOP; 0% SC. 6° slop stroke pattern: 73% ARC;
Post-Test N=26	wheelchair on a treadmill set to level, 3° and 6° grades.	23%SLOP; 4% DLOP; 0% SC. 4. From level to 6° slope: 63%
	semicircular (SC), single looping (SLOP), double looping (DLOP), arcing (ARC), Speed, Peak force, Push angle, Push	increase in peak force (p=0.000); 218% increase in peak force (p=0.000); 25.5% decrease in push angle (p=0.002); 21.6% decrease in push
	frequency, Power output.	frequency (p=0.042).

Author Year Country Research Design Score Total Sample Size	Methods		Outcome
		5.	Power output at 3° slope and 6° slope were 2.8 and 3.1 times higher than those at level (p=0.000).
Boninger et al. 2002 USA Post-Test N=38	Population: Mean age: 35.1 yr; Gender: males=27, females=11; Mean weight=167.2 lbs; Mean height=69 in; Handedness: left handed=5, right handed=33; Level of injury: paraplegia=38; Mean time since injury: 11.1 yr. Intervention: Self propulsion of personal wheelchair on a dynamometer at 0.9m/sec and 1.8m/sec. Outcome Measures: Stroke pattern – semicircular (SC), single looping (SLOP), double looping (DLOP), arcing (ARC); Axle position; Beginning stroke angle; Total stroke angle; Cadence; Mean velocity; Push time; Recovery time; Total time in propulsion.	1. 2. 3. 4.	Stroke patterns observed: 45% SLOP; 25% DLOP; 16% SC; 14% ARC. 58% used similar stroke patterns at both speeds, on both sides; however, the remaining subjects alternated patterns between sides and speeds. Most notably, SC pattern use decreased as the speed increased. DLOP and SC patterns had lower cadence than ARC (p<0.01) and SLOP (p<0.05). ARC and SC spent the most time in propulsion (p<0.05).

Discussion

There have been five studies that have investigated the effectiveness of stroke patterns in wheelchair propulsion in the spinal cord injured population. Boninger et al. (2002) studied the stroke patterns of 38 individuals with paraplegia while propelling their own wheelchair on a dynamometer at two different steady state speeds. The SC and DLOP patterns were found to have significantly lower cadence and least time spent in each phase of propulsion. The SC and ARC patterns had the greatest amount of time spent in propulsion relative to the recovery phase. A correlation has been found between cadence and the risk of median nerve injury (Boninger et al. 1999). The authors concluded a stroke pattern that minimized cadence may reduce the risk of median nerve injury.

Richter et al. (2007a) studied the stroke patterns of 25 individuals with paraplegia propelling their own wheelchairs at self-selected speeds on a treadmill set to level, 3° and 6° grades. In this study, the SC pattern was not used by any of the subjects. For level propulsion, the number of subjects using the remaining three patterns was fairly evenly distributed. However, once the subjects started going uphill 73% of participants used the ARC pattern. No significant difference was found in the handrim biomechanics between the different stroke patterns. The authors caution against training wheelchair users to adopt a certain pattern until more is known about the consequences.

Kwarciak et al. (2012) investigated the effects of the four different stroke patterns on hand rim biomechanics and upper extremity electromyography (EMG) in people experienced with w/c

use. They found variability in the participants' chosen normal propulsion stroke patterns, with 60% using a double loop pattern, 24% using the single loop pattern, and 8% each for using the ARC pattern and the semi-circular pattern. Despite the few significant values in the study, the authors felt the findings supported the recommendations for upper limb preservation that less frequent, long smooth strokes are required. The DL and SC patterns generated the best combination of biomechanics producing the longest contact angle, lowest cadence values, and smallest braking moments. While there were no significant values, the DL also has the advantage of 35% lower elbow muscle activity. However, the authors recommend that users individual style and comfort drive decision between the two (i.e., imposing changes from one pattern, as it produced the largest contact impact at the hand rim, the largest amount of muscle activation and the second worst values for cadence, peak force contact angle and braking moment. The arching pattern results in this study produced suboptimal handrim biomechanics but the low muscle demand is the most metabolically efficiency, to which the authors suggest may be useful for uphill propulsion.

Raina et al. 2012b identified the purpose of their study as threefold; 1) to determine whether the stroke propulsion pattern affects the magnitude of hand/forearm velocity prior to hand rim contact, 2) to determine if the hand movements of one of the four typical stroke patterns results in a higher effectiveness of propulsion and 3) if differences in propulsion patterns exist between participants with paraplegia versus tetraplegia. No differences were noted between patterns, but significant differences were found between the participant groups of paraplegia and tetraplegia. The differences were primarily in the wrist velocity prior to contact with the participants with paraplegia being more highly correlated to magnitude of force impact compared to the participants with tetraplegia, but both correlations being significant. The similar findings were found for effectiveness of impact forces, with the participants with paraplegia having significantly greater impact force effectiveness than participants with tetraplegia. Also noted was a difference in muscle activity particularly for the participants with tetraplegia having a higher radial force impact. The authors noted that the difference in radial force impact may be related to reduced force effectiveness in this group (i.e., weaker grip strength affecting sustained contact with handrim). Therefore, in this study, authors proposed that radial force may have been used by participants with tetraplegia to increase friction on the hand rim during the push phase. Given that in this study all participants with tetraplegia demonstrated low impact force effectiveness in all stroke patterns for propulsion, improving the effectiveness of the impact force or reducing the magnitude of impact force would require alternate means of increasing friction at the hand pushrim interface (e.g., friction gloves) or alterative mechanisms for propulsion (e.g., power assist wheels). These differences in the initial push phase of propulsion between paraplegic and tetraplegia injury levels hold important considerations for maintenance of upper extremity health.

Koontz et al. (2009) explored propulsion patterns, and kinetic and kinematic variables at start up propulsion over a linoleum floor, a carpeted floor and a 5° incline ramp with 29 people with spinal cord injury who used manual wheelchairs. They defined start up as the first three push strokes from a stopped position as most people reached average velocity of propulsion on similar surfaces based on other larger study results. The authors reported that some patterns were difficult to discern and some were hybrids of two propulsion patterns, therefore using three raters to gain consensus was recommended due to this variability. They found that on any surface, the most common first stroke pattern was an Arc, however those who switched after the first stroke to an under-rim pattern reached higher velocities and experienced fewer negative forces during start up than those who stayed with an Arc pattern. The only except to this was the ramp, where many participants continued to use the Arc propulsion pattern. The authors speculate this is related to the tendency of the wheelchair to roll backwards on the ramp during

the recovery phase; the Arc pattern has a shorted recovery phase. The impact of the first three stroke patterns on function and upper extremity maintenance is seemingly minimal until the consideration of the frequency of start/stop occurrences throughout the day is considered. The authors suggest greater attention needs to be paid to the propulsion to propulsion training particularly the patterns used.

Feng et al (2010) examined the kinematic differences between two stroke propulsion patterns (pumping and circular) with a focus on the glenohumeral joint excursion as related to shoulder impingement. Based on the research literature they defined impingement as "...contact between the anterior aspect of the humerus and the acromial arch which creates compressive forces on the glenohumeral joint" (p 448), with a range of internal or external rotation beyond 30° of forward flexion or 30° of abduction. The study wheelchair was adjusted for each participant for optimal propulsion positioning (i.e., 30° elbow flexion when hand on top of rim, distance between rear corner of seat and axis equaled 15% of participant's arm length). The authors concluded that the pumping stroke pattern of propulsion travelled more and stayed longer in the impingement range than the circular stroke pattern. The authors indicated that further study is required to determine if this range of glenohumeral joint excursion is related to shoulder impingement injuries, and if the use of the pumping stroke style contributes to shoulder impingement injuries. There are, however, a few limitations of this study, which make it difficult to generalize the findings to clinical practice. The first is the small study size (n=10). The second is the use of a pre-determined set up for the study wheelchair as opposed to examining the participant in their own w/c set up. The third is the use of only two stroke patterns, it is not clear why the authors identified only two stroke patterns and did not related them to patterns identified in the literature despite referencing articles where the four stroke patterns are identified. The fourth is the limited description of the amount of internal and external rotation that is considered as part of the definition of shoulder impingement.

Conclusion

There is level 4 (from four post-test studies; Boninger et al. 2002; Ritcher et al. 2007; Raina et al. 2012b; Kwarciak et al. 2012) evidence that the typical propulsion stroke patterns used by individuals with spinal cord injury varies across the four stroke patterns regardless of level of injury.

There is level 4 (from one post-test study; Boninger et al. 2002) evidence that the semicircular and double-loop-over propulsion wheelchair stroke patterns reduce cadence and time spent in each phase of propulsion, thus using these patterns may reduce the risk of median nerve injury.

There is level 4 (from two post-test studies; Ritcher et al. 2007; Raina et al. 2012b) evidence that there is no difference in hand rim biomechanics during propulsion between the four stroke patterns. However, there is also level 4 (from two case series studies; Boninger et al. 2002; Kwarciak et al. 2012) evidence that the semicircular and double-loop-over propulsion stroke patterns offer the best combination of biomechanics for propulsion.

There is level 4 (from one post-test study by Raina et al. 2012b) evidence propulsion biomechanics differ between people with paraplegia and tetraplegia with the latter group producing lower wrist velocity prior to contact, less magnitude of force impact, and higher radial force. There is level 4 (from one post-test study; Feng et al. 2010) evidence that the movements associated with particular patterns may increase the risk of shoulder impingement, with pumping stroke pattern exposing the shoulder to greater risk than the circular pattern.

There is level 4 (from two post-test studies; Kwarciak et al. 2012; Boninger et al. 2002) evidence that the ARC stroke pattern has suboptimal biomechanics, but the lowest muscle demand, therefore holds potential for making it useful for short duration, high force propulsions such during ascending a hill or ramp.

There is level 4 evidence (from two post-test studies; Koontz et al. 2009; Richter et al. 2007a) to suggest that the Arc pattern is the most frequently used propulsion pattern used when ascending a slope greater than 3°.

There is level 4 evidence (from one post-test study; Koontz et al. 2009) to suggest that it takes the first three propulsion strokes from a resting positioning to reach steady state velocity and while the Arc pattern is most frequently used for the first stroke, those who change to an under-rim pattern for the subsequent strokes, reach steady state velocities quicker and experience less negative mechanical forces during start up propulsion.

The evidence suggests that stroke pattern use varies based on individual preference and the environmental demands with some stroke patterns being more effective to achieve specific outcomes.

The evidence supports that to avoid accumulating shoulder impingement stresses proper technique must be considered based on a combination of kinematics (e.g., contact angle, stroke frequency, movement patterns at each joint), stroke pattern, wheelchair fit and set up.

3.1.2 Kinetics and Kinematics of Wheelchair Propulsion on Level Surfaces

This subsection focuses on research articles which examined the trunk and upper extremity kinetics (forces, mechanical loads, moments (torque)) and kinematics (movement at joints or between body segments) of manual wheelchair propulsion on level surfaces. Level surfaces included surface such as stationary treadmills, ergometers, and/or dynamometers and, smooth floor surfaces. The studies that follow examine propulsion more in-depth but each from a slightly different perspective, looking at slightly different parameters and environments.

Author Year Country Research Design Score Total Sample Size	Methods		Outcome
Qi et al. 2019 China RCT Crossover PEDro=6 N=11	Population: Mean age: 42.1 yr; Gender: males=8, females=3; Injury Etiology: SCI=9, Spina Bifida=2; Level of injury range (SCI AIS): T6-T12; Mean time since injury: 10.4 yr.Intervention: Participants performed a set of 3-min propulsion bouts at three different speeds: 1m/s (minimal safe speed to cross	1. 2.	Propulsion at 1.6m/s generated significantly higher EMG intensity in BB, AD, PM, and MD muscles than propulsion at 1m/s (p<0.05). Propulsion at 1.6m/s required significantly higher energy expenditure than at 1m/s (p<0.05).

Table 2. Trunk and upper extremity kinematics and kinetics during propulsion on level surfaces

Author Year Country Research Design Score Total Sample Size	Methods		Outcome
	an intersection with traffic lights), 1.3m/s (equivalent to able-bodied walking speed), 1.6m/s. The order of the exercise bouts were randomized with a 5min rest period	3.	No significant differences were found in peak resultant force, push frequency, and push length between propulsion speeds
	between bouts. Outcome Measures: EMG Measures: anterior deltoid (AD), middle deltoid (MD), postorior deltoid (PD) infraspinatus (IS)	4.	No significant difference in the average HR betweenpropulsion speeds, though HR showed an
	upper trapezius (UT), sternal head of the pectoralis major (PM), biceps brachii (BB), and triceps brachii (TB); Kinetics: peak	5.	Relative increase in BB, AD, PM, and IS activity in the early push phase and more activity in MD and PD during the
	(HR). Principal component analysis (PCA) to identify the impact of propulsion speed on shoulder muscle coordination.	6.	The transition between push and recovery phase at higher speeds is maked by increased activity of UT, MD, PD (recovery muscles) and AD and BB (propulsive muscles).
	Population: Mean age= 42 yr; Gender: males=16, females=5; Level of injury range: C6-L2. Intervention: Participants' manual	1. 2.	Participants had significantly less lordosis in the 14° condition for all propulsion events (p<0.05). Scapulothoracic internal rotation was
Cloud et al. 2017 USA RCT Crossover PEDro=6 N=21	wheelchairs (MWC) were modified to have seat dump angles of either 0° or 14°. Seating condition order was randomly assigned. Participants then completed 3 propulsion cycles in each condition to measure spine and shoulder motion data. Outcome Measures: Thoracolumar spinal curvature, glenohumeral kinematics, scapulothoracic kinematics: at start push (SP), midpush (MP), end of push (EP), mid recovery (MR).	2. 3. 4. 5.	increased in the 14° condition at SP and MP (mean differences of 2.5° and 2.7°, respectively). Relative downward rotation increased in the 14° condition at SP and MP (mean differences of 2.4° and 2.1°, respectively). No glenohumeral rotations were significantly different between the conditions. Lordosis differences were more pronounced in those with low SCI. Scapulothoracic differences were more pronounced in those with high SCI
Gil-Agudo 2014 Spain RCT PEDro=6 N=14	Population: Mean age: 35.2 yr; Gender: males=14, females=0; Mean time since injury: 90.2 mo. Intervention: Participants used a study wheelchair on a treadmill, with the propulsion power output monitored. Ultrasound screening was completed on the non-dominant shoulder before testing and immediately after each test protocol. Test protocols were completed with at least 48hr between them to ensure full recovery, Protocols were randomly assigned; one protocol was propulsion at high intensity with an incremental workload (start at 20W, increased by 5 W every 2 min until fatigue), the second protocol was propulsion at low intensity with constant workload (20W for	1. 2. 3.	In high intensity test, significant differences were found between early and late propulsion for all parameters analyzed (except adduction and abduction shoulder peak moments) (p <0.05). Increases in medial peak shoulder force were correlated with increases in long-axis biceps tendon thickness (LBTT) (p <0.05) and with decreases in sub-acromial space (p <0.05). Increments in biomechanical were higher in high intensity propulsion for all parameters (p <0.05) except lateral peak force (p =0.19) and peak
	maximum of 20 min). Outcome Measures: Shoulder joint kinetics measured using ultrasound screening technology; shoulder kinematics	4.	(p=0.06). No differences were found in ultrasound screening before and after each test protocol; effective

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	measured on the non-dominant side using four camcorders and passive markers placed at C7, left and right acromioclavicular joints the hand, forearm and arm, and the wheel hub. power output measured using the SMART ^{Wheels} ; Borg scale for fatigue.	mechanical force was similar in both protocols but increases in the forces and moments was greater in the high intensity protocol.
Julien et al. 2014 USA RCT Crossover PEDro=6 N=7	Population: Mean age: NR; Gender: males=5, females=2; Tetraplegia=7 (C5-7); AIS A=3, AIS B=2, AIS C=1, AIS D=1; Mean w/c use: 3.3 yrs. Intervention: Participants' normal speed of propulsion was established, with fast speed calculated as 20% above normal and slow speed as 20% below normal. Each participant was randomly asked to propel down a long hallway (smooth level surface) at one of the three different speeds for 10 sec. Three trials were done for each speed. Outcome Measures: A six-camera video motion capture system with reflective markers at vertex, left and right zygomatic process, left and right clavicle, sternum, C4, T4, T7 spinous processes and 3rd metacarpals, both w/c axles, and top of front caster barrels. Wireless speedometer. Measurements were of trunk motion relative to the w/c and neck motion relative to the trunk. Variables investigated included trunk flexion, lateral flexion and axial rotation, and neck flexion, lateral flexion and axial rotation. Movement were compared to propulsion cycle – push, recovery and total.	 At all phases of the push cycle, no identifiable pattern was evident for lateral flexion or axial rotation for either the trunk or neck. Participants fell into 1 of 2 groups; those who had substantial trunk and head movement regardless of speed of propulsion and those who had less movement in slow speeds but increasing movement with increasing speed. Some participants changed their stroke pattern with different speeds. Neck and trunk flexion significantly increased for all participants as speed increased (p=0.034 total push, p=0.031 for push phase). Forward flexion at the trunk or neck did not significantly increase during the recovery phase. Significant difference between slow and fast speed for neck flexion (p=0.018) and trunk flexion (p=0.016) with large effect size during the total propulsion (r=0.6, r=0.6) and push phase (r=0.5, r=0.6). Forward trunk flexion was significantly greater at fast speeds compared to slow speeds during the total propulsion cycle (slow=11.7±3.0°, fast=16.4±3.8, p<0.05) and during the push phase (slow=9.9±2.7°, fort=14.2+2.2°, p=0.05)
Triolo et al. 2013 USA RCT Crossover PEDro=4 N=6	Population: Mean age:46.2 yr; Gender: males=4, females=2; Level of severity: AIS A=3, AIS B=2, AIS C=1; Injury level: C6- C7=2, T5-T10=4; Mean injury duration=8.6 yr. Intervention: Participants received intramuscular electrode implantations at the L1-2 spinal nerves bilaterally to stimulate the lumbar erector muscles for trunk extension and intramuscular or epimysial stimulating electrodes to activate the gluteus maxmius muscles for hip extension. Participants propelled their own wheelchairs at a self-selected walking speed on a 10-m surface, a 100-m sprint, and a 30.5 m ramp (4.7% grade) incline. 20 trials of the self-selected speed condition	 For the self-selected walking speed, four participants did not experience significant changes in average velocity for self-selected walking speed between stimulation and no stimulation conditions (p>0.113) while 2 varied by <10%; no changes in average power between stimulated and non- stimulation condition. Peak resultant force during the contact phase decreased significantly with stimulation in three of the five participants (p<0.014); the other two had zero percent change with stimulation. Cadence and peak shoulder moment during stimulation increased

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	were completed, 10 with stimulation, 10 without. A trial consisted of 3-6 steady state cycles (i.e., stroke that was not transitioning from start or stop). The sprint condition consisted of three trials of stimulation and three without. Incline condition consisted of three trials each with and without stimulation, randomly assigned. Outcome Measures: Peak force, Peak shoulder movement, Fraction of electrical force (FEF), Average forward lean, Cadence, Stroke length, Usability rating scale (URS). Data gathered using SMARTwheel, vicon kinematic measures using reflective markers at key body points, Usability Rating scale.	 significantly in two participants (p<0.021, p<0.001). FEF and average forward lean increased significantly in the same three participants (p<0.048, p<0.001) during self-selected walking speed. Stimulation had no significant effects on cadence, stroke length, average velocity, and peak resultant force in any of the six participants during the 100-m sprint (p>0.05) or during the incline (p>0.397). In one participant, stimulation caused a significant decrease in FEF during the 100-m sprint (p=0.034). Combined data across the participants indicated that stimulation significantly affected overall kinetics and kinematics (p<0.001, F=7.679); there were no significant differences between trials with and without stimulation for the 100m sprint or the incline. Perceived effort as measured by the URS increased significantly post stimulation during the 100-m sprint (p<0.001).
Goins et al. 2011 USA RCT Crossover PEDro=6 N=7	Population: Mean age: 33.0 yr; Gender: males=5, females=2; Level of injury: C5=1, C5-6=1, C6=3, C6-7=1, C7=1; Severity of injury: AIS A=3, AIS B=2, AIS C=1, AIS D=1; Mean duration of manual w/c use: 11.1 yr. Intervention: Describe the linear and angular movements because of speed during manual wheelchair over ground propulsion in individuals with tetraplegia. Three speeds in random order on two different surfaces (40m of tile and of low pile carpet) using participants' own w/cs. Outcome Measures: Kinematic data collected using a video motion capture system: elbow translation in the anterior- posterior direction (cm), elbow translation in the medial-lateral direction (cm), elbow translation in the vertical direction (cm), and elbow angle. A wireless speedometer was used to capture speed.	 Right elbow anterior-posterior was significantly different during slow [26.7 (2.7)] and fast [31.3 (3.5)] and slow and normal [30.9 (2.6)] speeds. Right elbow translation vertically was significantly different between slow [7.5 (3.3)] and fast [9.6 (5.4)] speeds. Right elbow translation in the medial- lateral direction was significantly different between slow [13.1 (4.1)] and fast [14.7 (5.2)] speeds. No effect for speed during left elbow translation. No significant difference for elbow angle across speed. There were no significant differences examining the effects of speed on side- to-side (right versus left) elbow symmetry.
Gil-Agudo et al. 2016 Spain Prospective Controlled Trial N=34	Population: Manual Wheelchair (MWC) Group: Mean age= 35.5 yr; Gender: males=22, females=0; Level of injury range: T2-L3; Mean time since injury: 8.7 yr. Healthy Control Group: Mean age= 31.3 yr; Gender: males=12, females=0. Intervention: Subjects performed high- intensity wheelchair propulsion test on a treadmill (TM) to compare shoulder joint forces and moments as well as ultrasound	 High intensity propulsion results in greater shoulder forces and moments in almost all directions. No relevant change in ultrasound parameters following TM test. More shoulder pain according to the WUSPI or VAS was associated with a greater LBTT (p<0.05, respectively) for the MWC group.

Author Year Country Research Design	Methods	Outcome
Total Sample Size		
	changes. TM speed was set to achieve 20W for all subjects, increases of 5W were added every 2min. The trial was completed until participants could no longer propel their wheelchair. Outcome Measures: Shoulder pain: Visual Analog Scale (VAS), Wheelchair User's Shoulder Pain Index (WUSPI); Shoulder Joint Forces and Moments; and Shoulder Pathology via ultrasound examination: acromioclavicular distance (ACD): Cholewinski Index (CHI), Girometti Index (GI); long-axis biceps tendon thickness (LBTT); short-axis supraspinatus thickness (SST).	 Greater shoulder pain in the VAS was associated with a shorter ACD (p<0.05), and a larger SST (p>0.05). A statistically significant between group difference was found in LBTT relative change (p<0.05). The control group had a significant within group increase in GI (p<0.01).
Kim et al. 2015 Korea Prospective Controlled Trial N=16	Population: Paraplegic group (n=8): Mean age: 37.0 yr; Gender: males=8, females=0; Level of injury range: T1-T12. <i>Control group (n=8):</i> Mean age: 22.8 yr; Gender: males=8, females=0. Intervention: All participants propelled the wheelchair 200m three times at a comfortable speed on the ground. Electrodes were placed and recorded along different upper limb and neck muscles; Latissimus dorsi (LSD), Pectoralis major (PCM), Anterior/posterior deltoids (AD/PD), Triceps brachii (TRB), Extensor carpi radialis (ECR), and Sternocleidomastoid (SCM). Outcome Measures: Muscle activity using surface electromyography during the push phase of the propulsion cycle.	 There were no significant differences between the control and study groups in weight and height, (p>0.05) but the difference in age was significant (p<0.05). SCM activity was higher in the paraplegic group than the control group (p<0.05). LSD activity was higher in the test group than the control group but was not significant (p=0.07). There were no significant differences in any other muscle activities between groups (p>0.05).
Rodgers et al. 2000 USA Prospective Controlled Trial N=19	Population: Mean age:44.0 yr; Gender: males=16, females=3; Injury etiology: SCI=17, spina bifida=1, bilateral tarsal tunnel syndrome=1; Level of injury range: T3-L5; Mean duration of w/c use: 16.8 yr. Intervention: Participants propelled the study wheelchair at a velocity of 3 km/hr for 3min, then continued while load was added at a rate of 0.3 kg every 3 min until self- reported exhaustion was reached (i.e., unable to maintain target velocity) (GXT test). 2-7 days later participants completed the fatigue test where they rested for 6 min then propelled without a load for 3 min, and then continued propelling with the sub- maximal load (75% of peak VO2 from the GXT) until exhaustion reached. Participants were divided into two groups based on the angle of their trunk in upright sitting; if trunk was flexed more than 10° and/or those whose flexion increased more than 10° from fresh to fatigued states were in the flexion group (n=9). All others were in the non-flexion group (n=10). Wheelchair	 The only difference between the two study groups was concentric shoulder extension movement which was significantly greater in the non-flexion group than flexion group (p<0.04). The flexion group demonstrated significantly greater shoulder flexion and elbow extension than the non- flexion group at contact (p<0.006, p<0.013 respectively) and release (p<0.004, p<0.031 respectively). Joint kinetics revealed that the flexion group had significantly less posterior force (p<0.022) and significantly more medial force (p<0.046) at the elbow than the non-flexion group. The flexion group demonstrated significantly earlier cessations of flexor carpi ulnaris (p<0.001) and pectoralis major (p<0.031) muscle activity. Total biceps activity was significantly greater for the flexion group than the non-flexion group (p<0.034).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	propulsion was completed in a study wheelchair and on an ergometer. Kinematics were recorded in participants during fresh and fatigued states. Outcome Measures: Shoulder flexion and extension, Wrist flexion and extension, Elbow flexion and extension using a 3D cameras and video acquisition system, Force kinematics using a force/torque transducer in the wheel hub, Graded exercise test (GXT), VO ₂ max, Muscle activity using EMG.	 6. There were no significant differences between groups for resistance applied measured by the GXT, length of time in wheelchair, and VO₂ max during the fatigue test (p>0.05). 7. Both groups demonstrated significantly more shoulder flexion during contact (p<0.047) and at release (p<0.018), handrim force (p<0.03) when fatigued than in fresh state. 8. Both groups demonstrated significantly less wrist flexion (p<0.024), radioulnar shear force (p<0.022), peak amplitude of biceps (p<0.006), pectoralis major muscles (p<0.025), earlier onset (p<0.01). 9. Trunk flexion increased 7-10% for the FG group when fatigued; shoulder flexion increased by 6% when fatigued for the FG group but not the NFG group.
Jayaraman et al. 2015 USA Cohort N=22	 Population: Shoulder Pain (SP, n=10): Mean age: 25.8 yr. No Shoulder Pain (NP, n=12): Mean age: 22.0 yr; Injury etiology: SCI=13, spina bifida=5, spinal cyst=1, amputee=2. Intervention: Participants propelled their own manual wheelchairs fitted bilaterally with SMARTwheels on a roller dynamometer for 3 min at a pace of 1.1 m/s. Data was collected during propulsion (push phase and recovery phase) after participants had a chance to acclimatize to the dynamometer. Outcome Measures: Kinematic data was collected using a 10-camera motion analysis system, with 18 markers on body and wheelchair. Kinetic data was collected using the SMARTwheel. Data collected included: peak force, push time, contact angle and push speed, peak resultant force at and rim; recovery phase (hand movement after propulsion) kinematics; and jerk kinematics of the wrist, elbow and shoulder joints. Data related to shoulder pain was collected using a visual analog scale (VAS) and for those who indicated shoulder pain, further data was collected using the wheelchair user's shoulder pain index (WUSPI). 	 No significant differences between groups in demographics as a function of recovery phase stroke pattern of shoulder pain (p>0.05); no differences noted in shoulder pain (as measured by the WUSPI) between the two stroke pattern groups. No significant differences between recovery phase patterns were observed in regard to peak resultant force, push speed or contact angle (p>0.05). Peak magnitude of the absolute jerk (Pmax) for the participant with shoulder pain was lower than for those without pain. Push time was significantly greater in patients that used a semi-circular (SC) recovery phase pattern compared to a double loop (DLOP) pattern (mean SC=1.12±0.04 m/s, DLOP=1.17±0.08 m/s). Significant main effect of both recovery phase patterns was observed for jerk criteria at the wrist (p<0.05), elbow (p=0.05), and shoulder joint (p<0.05). Significantly lower mean jerk criteria were observed for patients using a SC pattern compared to the no pain group for the wrist (p<0.05), elbow (p<0.05) and shoulder joints (p<0.05).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
		 No significant differences were observed between SP and NP groups in regard to peak jerk criteria (70- 100%) (p>0.05).
Champagne et al. 2016 Canada Pre-Post N=13	 Population: Mean age= 40.4 yr; Gender: males=10, females=3; Level of injury range: C5-T11; Mean time since injury: 3.1 yr. Intervention: Cardiorespiratory demand and rate of perceived exertion were measured for manual wheelchair (MWC) users with and without traction by a mobility assistance dog (MAD). The course used had level propulsion, followed by an inclined concrete ramp, and finally level propulsion. Outcome Measures: Oxygen Consumption (VO2), Ventilation (VE), Tidal Volume (VT), Respiratory Quotient (RQ), Respiratory Rate (RR), Heart Rate (HR), Time, Perceived Rate of Exertion (RPE). 	 Significant reductions were observed in all cardiorespiratory and heart rate measures when participants completed course with MAD (p<0.05). Participants RPE was significantly improved with the use of a MAD (p≤0.001). Significantly less time was required to complete the course with the use of a MAD (p=0.0007).
Gagnon et al. 2016 Canada Pre-Post N=15	Population: Mean age= 32.7 yr; Gender: males=14, females=1; Level of injury range: C8-T12. Intervention: Manual wheelchair (MWC) users performed three propulsion tests (MWPT): 20m Test, 18m Slalom Test, and 6 min test. Tests and measures were completed within 72 hours prior to discharge from inpatient rehabilitation program. Outcome Measures: Upper Extremity (U/E) strength, Trunk strength, Seated reaching capability. Bivariate correlation and multiple linear regression analyses to ascertain best determinants and predictors of wheelchair propulsion performance.	 MWPT performance was moderately or strongly correlated with anterior and lateral flexion trunk strength, anterior seated reaching distance, and shoulder, elbow, and handgrip strength measures. U/E strength best predicts the 20 m Propulsion Test, with shoulder adductor strength on the weakest side best predicting performance at maximal velocity. U/E strength and seated reaching capability best predict the Slalom Test, with shoulder adductors on the strongest side and forward reaching being the two key predictors. Handgrip strength best predicts the 6- Minute Propulsion Test.
Russell et al. 2015 USA Pre-Post N=40	Population: Mean age: 35 yr; Gender: males=32, females=8; Level of injury range: T2-L3; Mean time since injury: 8.3 yr. Intervention: Upper extremity kinematics and pushrim reaction forces were measured for participants on a stationary ergometer at self-selected free and fast propulsion speeds for 40 sec (data collection at last 10 sec or 6-10 push cycles) for each speed condition. Participants used their own manual wheelchairs except for 13/40 as their wheelchairs didn't fit on the ergometer; in these cases, they used a study wheelchair that was set up to match their own.	 Wheelchair propulsion speed significantly increased between free and fast conditions across all participants (p=0.0001); mean velocity at self-selected free condition was 1.02±0.3 m/s, during fast condition was 1.72±0.3). The average increase from free to fast propulsion was 0.70±0.2m/s. Duration of hand rim contact significantly decreased across all participants during fast propulsion (p=0.001) and resultant Reaction Force magnitude (RF) increased significantly for fast propulsion as compared to free propulsion, across all participants (p=0.001). With-in

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Outcome Measures: Wheelchair propulsion speed, Net joint movement (NJM), Net joint force (NJF), reaction force orientation, forearm orientation, elbow angles. Outcomes were measured using a SMARTwheel, and a CODA motion analysis system.	 group comparisons showed that 26 of the 40 participants increased resultant RF magnitude with 22 of these increasing the RF force by 10 N or more. 3. Resultant reaction force magnitude, resultant shoulder NJM and NJF at time of peak push increased significantly for the fast as compared to the free speed condition for all participants (p=0.0001). With-in participants (p=0.0001). With-in participants increased shoulder NJM during fast propulsion condition with 15 of these increasing NJM by 10 Nm or more. NJF increased on average by 23N or more in the fast condition. 4. No significant differences in elbow angle at peak push between fast and free speeds (p=0.05).
Soltau et al. 2015 USA Post-Test N=80	Population: Mean age: 37.0 yr; Gender: males=74, females=6; Mean disease duration=9.0 yr. Intervention: Participants used their wheelchairs on a stationary ergometer in three conditions: level propulsion at self- selected speed (free), fastest comfortable speed (fast), and an 8% graded speed. A 10 second trial was recorded for each condition, with data being collected separately for the left and right sides. Kinematics were recorded via an instrumented handrim (SMARTwheel) and a motion capture system (CODA system) between dominant and non-dominant sides. Outcome Measures: Joint kinematics (elevation plane ROM, elevation angle ROM, shoulder rotation ROM, elbow flexion ROM, forearm protonation ROM); Handrim kinetics (Average total force, average tangential force, peak total force, peak tangential force, fraction of effective force (%); Spatiotemporal variables (Cycle time, push percentage, push angle, net radial thickness (NRT), total radial thickness (TRT)).	 The following outcome measures were significantly greater for the dominant side in the graded conditions: Elevation plane ROM (p=0.006), shoulder rotation ROM (p=0.002), forearm protonation (p<0.001). Elevation angle ROM and elbow extension ROM was significantly larger on the dominant side than non- dominant side (p=0.015, p=0.044). There were no significant main effects in any of the handrim kinetic variables (p>0.05). Push angle had a significantly larger dominant side value in the graded condition (p=0.025).
Yang et al. 2012 USA Score Post-Test N=36	Population: Mean age: 39.0 yr; Gender: males=26, females=10; Level of injury: T8- L2; Mean time since injury: 11.8 yr; Duration of w/c range: 2.7-32.1 yr. Intervention: Propulsion biomechanics for two different back support and back support frame heights (16"&½ of participants back height) on two different	 With the low backrest set up push times were longer (p<0.01), cadence was lower (p=0.01), stroke angles were larger (p<0.01), start position was further back on rim (p=0.07), and release was further forward on rim (p<0.01).

Author Year Country Research Design Score	Methods	Outcome
	slopes (0°&3°) on a w/c treadmill. Participants used a standard study w/c and no cushion. Protocol: 2 min propulsion for warm up followed by 30 sec of each of four test situations, with a 5 min rest in between. Outcome Measures: Instrumented rear wheel (SMART wheel) captured propulsion kinetics; six camera Qualisys motion analysis system to capture body movement; outcome measures were: cadence, stroke angle, peak shoulder extension angle, shoulder flexion/extension range of motion and mechanical effective force.	 Average height of low back rest was 27.6±3.2 cm compared to the 40.6cm (16") length of the high back support Significantly larger shoulder extension angles at start of push (p=0.02); greater shoulder range of motion (p<0.01) with lower backrest. No significant effect of backrest height on propulsion kinematics Increased slope resulted in increased cadence (p<0.01), start and end angles were smaller (p<0.01), greater range of shoulder flexion/extension motion (p<0.01), greater resultant force (p<0.01), tangential force (p<0.01), propulsion torque (p<0.01) and Mechanical effective force (p<0.01). No interaction effects between back support/back support frame height and angle of slope.
Raina et al. 2012a USA Post-test N=18	Population: Mean age: NR; Gender: males=18, females=0; Level of injury: T1- T12=11, C6-C8=7; Range of time since injury: 5-28 yr. Intervention: A study w/c (lightweight, rigid frame) was used on a stationary ergometer with limited adjustments for each participant. Participants were strapped to the back of the w/c as requested for additional balance support. Motion analysis system to capture body motion; Instrumented wheel (SMART wheel) to capture forces at the hand rim in 2 differenet load conditions. Outcome Measures: Rotation of the scapula at peak force [anterior posterior (A/P) tilting around the medial-lateral axis, upward/downward (U/D) rotation around the anterior-posterior axis and retraction/protraction (R/P) around the inferior-superior axis].	 Push phase average peak resultant forces at the hand rim were significantly higher (p<0.05) for all participants for the loaded condition. Participants with paraplegia exhibited significantly more downwardly rotated (p<0.05) and less retracted (p<0.05) scapula during loaded condition compared to non-loaded. Additionally, a range of 5°-15° of scapular motion in the A/P and P/R direction under the loaded condition was noted compared to 5° ROM during the level condition. Rate of change in scapular movements was significantly higher (p<0.05) during the loaded condition) but only in the P/R direction Participants with tetraplegia exhibited variations in scapular movement, with 3/7 having an upwardly rotated scapula and the rest having downward rotation. On average, there was less retraction during the loaded condition compared to the non-loaded. Similar changes with scapular range were observed as for participants with paraplegia. Rate of change in scapular movement was significantly higher (p<0.05) in loaded condition for the U/D and P/R directions. Between the patient populations, under the loaded conditions the scapula of participants with tetraplegia showed a significantly higher rate of anterior tilting that those with

Author Year Country Research Design Score Total Sample Size	Methods		Outcome
			paraplegia but no other significant differences were noted.
Koontz et al. 2012 USA Post test N=24	Population: Mean age: 40.0 yr; Gender: males=21, females=3; Level of injury: C=7, T=13, L=2, 2=other (not SCI); Mean duration of wheelchair use: 17.0 yr. Intervention: (1) investigate the relationship between key kinetic and temporal discrete point variables and (2) compare qualitative and quantitative characteristics of the force and movement curves between a dynamometer and a level smooth surface (tiled over ground). Outcome Measures: Kinetic data: maximum resultant force (FR), radial force (Fr), tangential force (Ft), medial-lateral force (Fz), movement about the hub (Mz); push angel; stroke frequency; average wheel velocity; and average mechanical effective force (mef). Experimental set-up included a dynamometer designed in house (2 independent steel tubular rollers, one for each wheel) and for the overland portion, two instrumented wheels (SmartWheel) attached to individual's own wheelchair.	1. 2. 3. 4. 5. 6. 7. 8.	Individuals produced larger peak force on the dynamometer compared to tile over ground. All kinetic outcome variables were positively correlated for the two surface conditions except peak Fz. Self-selected velocity for tile was higher than for the dynamometer and was not correlated. Mechanical efficiency, push angel, and frequency were positively correlated between conditions. Subject body weight was significantly correlated with all maximum forces and Mz (movement around the hub) except Fz force for both surfaces (r ranging from 0.427 to 0.783, p<0.01) and Fr for the dynamometer (R ranging from 0.467 to 0.623, p<0.01). The dynamometer maximum resultant force and body weight best predicted maximum resultant force on tile (R=0.826, p<0.001). Mz curves (moment about the hub) were normalized and positively correlated between surfaces (R ranging from 0.74 to 0.00, p<0.001). There was significant association between curve type (bimodal, unimodal and flat) and surface using chi-square test (x ² =9.489, p=0.008); bimodal was most common on the dynamometer and unimodal was most common on the tile.
Gil-Agudo et al. 2010 Spain Post-test N=16	Population: Age range: 18-65 yr; Level of Injury: T1-T12; Severity: AIS A or B; Time since injury: ≥6 mo. Intervention: Participants complete propulsion trials on a treadmill using a standard lightweight study wheelchair; a 2 min adaption period followed by 1 min at 3 km/hr, 3 min rest, and 1 min at 4 km/hr. Outcome Measure: Right shoulder joint net forces and moments as measured by a right side instrumented rear wheel on a study w/c, and a set-up of four video recorders and reflective markers on the hand, forearm, arm, trunk and AC joint. Joint net moments were referenced to the trunk not the humerus. Measurements included: cadence, total force (Ftot) propulsion moment (Mp moment around the hub) and tangential force (Ft).	 1. 2. 3. 4. 	Changing propulsion speed from 3 to 4 kmh ⁻¹ increased cadence, Ftot, Ft, and Mp (p<0.01), as well as the propulsion angle (p<0.05), whereas the release angle decreased (p<0.01). During the push when increasing propulsion velocity, both maximal (anterior direction) and minimal peak (posterior direction) shoulder forces of Fx were increased (p<0.01), whereas for Fy maximal value decreased and minimal value increased its magnitude (both inferior direction, p<0.05). During the recovery phase both maximal (posterior direction) shoulder forces of Fx were increased (p<0.01). Maximal (lateral direction) and minimal (anterior direction) peaks were also increased for Fz (p<0.05) During the push when increasing propulsion velocity maximal

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Population: Gender: males=16, females=0: Able bodied (AB: n=5): Mean	 (adduction) and minimal (abduction) Mx peak, My peak (internal rotation), and Mx peak (flexion) values improved (p<0.05). 5. During the recovery phase, minimal Mx peak (abduction) and My maximal peak (internal rotation, p<0.05) increased. Kinematics: The average propulsion cycle duration
Bregman, 2009 Netherlands Post-test N=16	Temales=U; Able bodied (AB; n=5): Mean age: 22.0 yr. Paraplegia (PP; n=8): Mean age: 39.0 yr; Injury level: T3-T12; Mean time since injury: 14.0 yr. Tetraplegia (TP; n=3): Mean age: 28 yr; Injury level: C6-C7; Mean time since injury: 7 yr. Intervention: Participants propelled an instrumented wheelchair on a level treadmill simulating a low load for 30sec at a constant pace while 3D external forces and moments, and 3D kinematics of the right upper extremity Compared forces of tangential propulsion with total propulsion force (experimental condition). Data gathered for forces was inputted into the Delft Shoulder and Elbow Model (DSEM) to calculate physiological cost/demands to calculate mean glenohumeral contact force, net joint moments and muscle powers. Outcome Measures: Kinematic and kinetic data, Physiological cost, Moments, Muscle powers, Glenohumeral contact forces, Percentage of glenohumeral constraint activity. Tools used: Standard study wheelchair with six-degree-0f- freedom force transducer, Optotrak motion analysis system using 17 active markers of the body and wheelchair, Delft Shoulder and Elbow Model (DSEM).	 The average propulsion cycle duration was 1.34 (0.27), which was comparable for the three groups (AB, TP and PP). The push phase of the propulsion cycle represented 51.7% (6.3) of the entire propulsion cycle. Kinetics: No significant differences in the magnitude of exerted force were found between the three subgroups; mean force=18.8(0.27) N. No significant differences in the magnitude of the tangential component and the FEF (11.7(2.8) and 63.2(12.6%) respectively) were found between the three subgroups. Results from the DSEM: No significant differences in increase in physiological cost found between three groups (p=0.58). Both the produced energy and the dissipated energy of all muscles were significantly higher in the tangential force condition (p<0.01). The mean peak glenohumeral contact force was significantly higher in the tangential force condition (p<0.01) but no significant difference between the three subgroups (p=0.92). The glenohumeral contact force was peaked in the middle of the push phase for both conditions; however, the force was higher for the duration of the push phase. No differences were noted between groups.
Mercer et al. 2006 USA Post-test N=33	Population: Mean age: 37.8 yr; Gender: males=23, females=10; Level of injury: below T1; Mean time since injury=12.4 yr. Intervention: Participants propelled their own w/cs on a dynamometer set to mimic the resistance of a tile floor at speeds of two mph and 4mph. Data was captured for 20 sec once a steady state speed was reached, with 1min rest periods between	1. All participants except one presented with 1+ abnormality in the MRI results with all pathologies present (except osseous spur) in at least half of participants; distal clavicular edema=55%, AC joint DJD=52%, AC joint edema=58%, Osseous spur=30%, entheseal edema=67%, CA ligament

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	trials; the number of trials was not provided. Outcome Measures: 1) Magnetic Resonance Imagining (MRI) of non- dominant shoulder for eight rotator cuff pathologies, scored on a 4 point scale (0=absent; 1=mild; 2=moderate; 3=severe); 2) Physical examination for signs of shoulder pathology related to pain or discomfort during resisted abduction and internal rotation, resisted internal rotation, resisted external rotation, resisted abduction, palpation of the sub- deltoid bursa and biceps tendon as measured on a 3 point scale; 3) Motion Analysis System to track movement and moments of upper extremity with five markers on the body and markers on the wheel hub (# not stated); 4) two instrumented rear wheels placed on participants own w/c to measure forces and moments during propulsion; measurements were used only from the non-dominant side.	 edema=89%, CA ligament thickening=64%. Physical exam scores ranged from 0 to 10 with an average score of 1.03, the mode and median scores were 2; 30% of participants expressed discomfort during the physical exam. Age was not significantly related to the physical exam score or any MRI score Participants' mass was significantly associated with the physical exam (p=0.05), acromioclavicular joint edema (p=0.04) and coracoacromial ligament thickening (p=0.02); higher body mass increases the odds of having shoulder pathology as indicated by a physical exam; higher body mass associated with increased association with posterior force (p=0.007), lateral force (p=0.006), internal rotation moment (p=0.02) and extension moment (p=0.009). Speed significantly increased all biomechanical variables (p<0.01) for posterior force, superior force, lateral force abduction moment, internal rotation moment, extension moment, stroke frequency and mean velocity. Age did not significantly influence shoulder force and moments but was associated with increased stroke frequency (p=0.006) and lower mean velocity (p=0.07). Dichotomized MRI and physical exam results compared to biomechanical variable indicated that participants with 1) higher posterior forces had significantly higher prevalence of coracoacromial ligament edema, (OR=1.29, p=0.03); 2) higher lateral forces were more likely to have CA ligament edema (OR=1.35, p=0.045) and CA ligament thickening (OR=4.35, p=0.045); 3) Internal rotation moment increased odds of pathology signs in the physical exam.
Ambrosia 2005 USA Post-Test N=22	 Population: Mean age: 43.0 yr; Gender: males=16, females=6; Mean time since injury: 16.6 yr; Level of injury range: T2 to L1. Intervention Participants' muscle strength was measured first with five measured of maximum effort in flexion/extension, abduction/adduction, internal and external rotation, from which muscle ratios were calculated. Following this testing, participants propelled their wheelchair on 	 Strong relationship between right and left sides for shoulder isokinetic torque values (p=0.001). For pushrim values, right and left sides correlated for all variables (p=0.001). Significant correlation between pushrim variables for 0.9m/s trial ad 1.8m/s trial (p<0.001 for FR, Ft, Fr and Fz).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	treadmill at a comfortable speed for 3-5 min, and then performed two trials at 0.9 m/s and 1.8 m/s for approximately 60 sec. Strength and pushrim biomechanical variables (tangential (motive) force (Ft), radial force (Fr), axial force (Fz), total (resultant) force (FR), fraction of effective force (FEF), and cadence) were correlated. Outcome Measures: Kinematic data was collected using the OPTOTRAK system of 3-dimensional motion analysis and kinetic data (Shoulder strength, torque) was collected using the SMARTwheel.	 Ft, Fr, and FR were significantly correlated with all muscle strength variables (p<0.05). Fz, FEF, and cadence were not correlated with any of the strength variables (p>0.05). None of the muscle ratios were significantly correlated to pushrim variables (p>0.05). Abduction was 15% greater than adduction. Shoulder isokinetic peak torque: flexion was 51% greater compared to extension; internal rotation was 13% greater than external rotation.
Dallmeiijer, 1998 Netherlands Post-test N=29	 Population: <i>Tetraplegia (1P; n=17):</i> Mean age: 34.3 yr; Gender: males=16, females=1; Mean weight: 78.1 kg; Level of injury: C5-C7; Mean time since injury: 7.3 yr. <i>Paraplegia (PP; n=12)</i>: Mean age: 39.8 yr; Gender: males=10, females=2; Mean weight: 80.3 kg; Level of injury: T5/6-L3/4; Mean time since injury: 1.7 yr. Intervention: All subjects performed a maximal exercise test on a wheelchair ergometer using a study wheelchair that was adjusted to standard set up for each participant. Two 1 min exercise bouts were used for analyses (30 to 50% and 60 to 80% of the maximal power output) to examine effectiveness of force application, ratio power output/energy expenditure and timing parameters of wheelchair propulsion in persons with TP and PP. Velocity was standard for each group (1.11 m/s PP; 0.83 m/s TP and prolusion was until exhaustion.) Outcome Measures: Forces (3D force application (N) Fx, Fy, Fz – horizontal forward, horizontal outward, vertical downward respectively), Direction of force application DAxz (tangential force), DAyz (place of the wheel) velocity, power output (PO), Hand position data (beginning angle (BA), End angle (EA), Stroke angle (SA), Cycle time (CT), Push time (PT)), Oxygen uptake. Outcome tools used: 2D video recording system, Forces at the rear wheel gathered through the ergonmeter, Oxycon Ox4. 	 Mean maximal exercise test duration was 7.3±2.0 min for TP and 8.1±1.9 min for PP. POmax showed a significantly higher value in PP (63±3W) compared with TP (19±10W) (p<0.05); mean velocity remained constant over the test condition for both groups. Effectiveness of force application: a) no differences between groups for Fy; b) Fy relative to F to tpeak significantly higher force in TP (p<0.05); Fymean showed a positive force in PP and negative in TP (p<0.001); c) Fymean and Fypeak showed significantly higher force at high intensity condition (p<0.05); d) with increased load, significant increase seen (p<0.001) between groups. Direction of force application (based on only 16 participants due to technical errors): A0 DAyz was significantly higher in TP (p<0.05); b) In the high intensity condition DAxz significantly lower (p<0.05) but DAyz showed no significant differences suggesting forces were applied more effectively in the plane of the wheel at high intensity. Ratio power output/energy expenditure: a) was considerably lower in TP compared to PP (p<0.01); power output/energy expenditure increased significantly; b) a higher load in both groups (p<0.01). Timing and stroke angle: a) TP compared to PP showed a larger BA (p=0.042), and a longer cycle time (p=0.003) and push time (p<0.001) b) The effect of intensity on (SA) was significantly different between TP and PP (p=0.032) c).

Author Year Country Research Design Score Total Sample Size	Methods		Outcome
		8. 9.	(BA) showed a shift forward at the high intensity condition for both lesion groups (p=0.006) d). Cycle time tended to decrease (p=0.070), whereas push time increased significantly (p=0.023) at the higher intensity condition.
VanLandewijck et al. 1994 Belgium Post-test N=40	Population: Mean age: 31.8 yr; Mean weight: 68.11 kg, Mean time since injury:18.38 yr; Injury etiology: Polio myelitis=13, spina bifida=2, hip disarticulations=2, below the knee amputee=1; Level of injury range: T3-L5. Intervention: Participants used a standard test wheelchair on a treadmill to perform a maximal test and then four submaximal tests, at least 1hr post maximal. At each stage of the maximal test the load was increased for 4min followed by a 2-min active recovery period without the additional load. During the last minute of each stage Metabolic, Kinematic and EMG data was taken for 8.2 sec simultaneously. After a period of at least 1 hr, participants were put through four submaximal tests, each 6min in duration. These tests were done at two different velocities and were performed in a random sequence. The velocities were tested against two levels of power output (60% and 80% of each individuals' peak-VO ₂). Outcome measures: Metabolic Data: Minute ventilation, Oxygen uptake, Carbon dioxide output, Respiratory exchange ratio, Heart rate, Gross mechanical efficiency, Kinematic Data hand contact, Hand release, Push time, Recovery time, Cycle time, Cycle frequency, Start angle, End angle, Push angle, Trunk inclination, Lateral humeral epicondyle, , Ulnar styloid process, a dnrear wheel axle, Mechanical Work, EMG data at biceps, Triceps, Brachialis longum, Decapods, Latissimus dorsi, Trapezius.	 2. 3. 4. 	Gross mechanical efficiency did not exceed 11.5%. Increased energy consumption and significant decreases in efficiency were noted with increased velocity to 60% level (p=0.001) and 80% level (p=0.001). Some participants reached maximum oxygen consumption when their wheelchair was at 2.22m/s at 80% exercise level. Cycle time and Push time both decreased as velocity increased across both exercise levels but recovery time remained constant. Cycle frequency and End angle both increased as velocity went up across both exercise levels. Start angle, Push angle and Trunk range of motion all vary across the increasing velocities of both exercise levels. As the velocity increased the distance that the hand traveled during the recovery period also increased at 60% exercise level. Peak activity for Biceps brachialis muscle was at initial hand contact, activity of triceps brachialis increased progressively reaching maximum value at hand release. Pectoralis major, Deltoids anterior and Latissimus dorsi all reach their max levels during push phase. Deltoids medialis and posterior and Trapezius all reach maximum activity during recovery phase.

Summarized Level 5 Evidence Studies:

The following level 5 evidence studies have been reviewed, and the overarching findings from the studies are highlighted in this section. As noted at the start of this chapter, these types of studies are not included in the discussion or in the conclusions.

Mulroy et al. (1996) examined 12 deep and superficial muscles of the shoulder of 17 men with complete paraplegia (T10-L3) during wheelchair propulsion, to identify which muscles might be at risk for fatigue and overuse. Using electromyography, the activity in each muscle was recorded and determined as having mainly push or mainly recovery activity. The authors identify "two synergies of shoulder muscle function during wheelchair propulsion"; push phase was

primarily shoulder flexion and scapular protraction, the recovery phase extension, abduction and scapular retraction. The authors' noted that the cadence for wheelchair propulsion averaged 67 cycles per minute, thus is a repetitive activity. The authors identified that the supraspinatus and pectoralis major muscles may be at higher risk of fatigue due to their involvement in both cycles of propulsion and their high peak intensities during the push phase.

Desroches et al. (2010) described the upper limb joint dynamics during propulsion of a manual wheelchair, particularly the contribution of joint moment to joint stabilization. Their findings indicated that stabilization during propulsion and recovery phases were a large component of the joint forces and moments. Findings indicate that during propulsion, wrist and elbow joints were in the stabilization configuration of wrist extension, ulnar deviation and elbow adduction (angles close to 90°) while the shoulder flexion was in a propulsion configuration but approached the stabilization configuration of flexion and internal rotation (angles primarily greater than 60°). The authors conclude that these results confirm their hypothesis that an important part of joint moment is the contribution to stabilizing joints, in addition to contributing to the force to create propulsion. The authors further discuss how from a mechanical point of view this could be perceived as inefficient however; from an anatomical point of view stabilization is essential to support movement as well as maintaining the integrity of the joint during force application such as during wheelchair propulsion. The authors question if this partially explains the low mechanical efficiency of manual propulsion, and the potential for injury at these joints.

Goins et al. (2011) described the horizontal and vertical translation of the elbow and elbow angle during three different speeds of propulsion (participants' own normal, 20% less than normal and 20% more than normal) on two different surfaces (tile & low pile carpet) for people with tetraplegia. Three distinctive elbow movement patterns as well as three distinct elbow angle patterns were noted amongst the seven participants. With this limited number of participants is it difficult to surmise if these are typical patterns or if with an increase in number of participants if the number of patterns would also increase. The primary finding from this study was that with increased speed elbow translation changes, but the range of elbow flexion remained consistently within a mid-range.

Discussion

Upper extremity kinetics and kinematics during propulsion

VanLandewijick et al. (1994) studied the movement and muscular activity of the upper extremity during the push and the recovery phases of propulsion at three different speeds on a treadmill. The participants were 40 "highly trained" athletes with diagnoses of T3-L5 spinal cord injury (n=22), polio myelitis (n=13), spinal bifida (n=2) and lower limb amputation (n=3). The results were analyzed separately as push phase and recovery phase. The results indicate that the amount of elbow movement is dependent on the velocity of the push, with the amount of elbow extension decreasing as velocity increases. The results also indicated that the shoulder was in near maximum abduction at the point where the hand contacts the push rim and that as velocity increased the range of shoulder motion in the first half of the push cycle increased but decreased in the second half. Trunk inclination range did not change however the amount of time in the forward range increased at higher push velocities. Results related to the recovery phase suggest that positive mechanical work exists during this phase at velocities higher than 1.67 ms, approaching one-third of the entire mechanical work of the full propulsion cycle.

Kim et al. (2015) compared the neck and upper limb muscle activity of eight participants with T1-T12 paraplegia with eight able-bodied participants using electromyography. All participants

received wheelchair propulsion training such that they could propel 200 meters in 1.5 to three minutes. Test conditions were propelling 200 m three times. The only difference in muscle activity of significance was that of the sternocleidomastoid muscle being more active in the test group. The authors note that the latissimus dorsi muscle was also more active in the test group than the control group, but it did not reach significance. The authors reported that these findings suggest that training and therapy should include education and treatment for the sternocleidomastoid muscle to reduce overuse and possible symptoms similar to visual display terminal syndrome.

Mercer et al. (2006) examined shoulder forces and moments during propulsion at two speeds to determine if biomechanics were related to shoulder injury pathology as identified from MRI and physical exam results. Findings suggest that body mass is associated with higher forces (posterior and lateral) and moments (internal rotation and extension) during the push phase of propulsion therefore higher mass is associated with increased risk for shoulder pathology especially acromioclavicular joint edema or coracoacromial ligament thickening. Findings also suggest that increased speed results in increased stoke frequency and use of larger shoulder forces and moments. Participants' who used higher posterior force, lateral force or extension moment during propulsion were more likely to have CA ligament edema noted on the MRI; those who used larger lateral forces or abduction moments were more likely to have CA ligament thickening noted. Participants who used higher superior forces and internal rotation moments during propulsion showed signs of shoulder pathology in the physical exam. The authors suggest the necessity for interventions to reduce the forces and moments such as the use of lightweight wheelchairs to reduce rolling resistance and the forces required to propel, as well as proper set-up, body weight maintenance, training in propulsion techniques or alternative methods of propulsion.

Similarly, Gil-Agudo et al. (2014) examined the acute changes of the shoulder cuff soft tissue pre and post wheelchair propulsion at two different speeds but used ultrasound technology. Results indicated that joint forces were stronger in all directions and most moments in the higher intensity propulsion protocol, but the ultrasound parameters were not different before and after each test. Relating kinetic and ultrasound results indicated that high intensity propulsion increased long biceps tendon thickening when medial and inferior forces increased, and that the subacrominal space decreased with increase as the propulsion intensity increases which may contribute to the development of shoulder pain.

Bregman et al. (2009) compared total propulsion force to tangential propulsion force in 16 participants (five non-disabled, three with tetraplegic level of SCI, eight with paraplegic level of SCI) to determine if the tangential propulsion force results in a greater physiological cost that the total propulsion force (experimental condition). Participants propelled a study wheelchair on a level treadmill for 30 seconds; data from 10 consecutive propulsion cycles was used which was resampled to 100 samples for comparison and averaging. The kinetic and kinematic data was then inputted into the Deflt Shoulder and Elbow model to determine the physiological cost of the two conditions. The results of the kinetic and kinematic data indicate that: 1) the average propulsion cycle was 1.34(0.27) seconds for all three participant groups; 2) the push phase was 51.7(6.33) % of the full cycle; 3) mean force at exerted on the handrim was 18.8(4.7) N with no significant differences between groups; 4) the tangential component of the propulsion force was 11.7(2.8) N resulting in an fraction effective force (FEF) of 63.2(12.6)%, but no significant differences between groups were found. The authors report that based on the output from the DSEM, that the efficiency in manual wheelchair propulsion is related to the co-contraction around the elbow and the higher energy requirements of the shoulder during tangential

propulsion compared to the experimental condition. Generally, the results indicate that the forces and moments in tangential propulsion are higher, often significantly higher compared to the total propulsion forces. The authors suggest that propulsion training should therefore not be focused on optimizing force but more so on finding the balance between the direction of force application on the hand rim and the musculoskeletal constraints of the person propelling.

Ambrosio et al. (2005) sought to determine if a correlation existed between shoulder strength and hand rim kinetics and between muscle imbalance and hand rim kinetics. The authors support that based on the finding of a positive correlation between strength and total resultant force (FR) at the hand rim, and that there was no correlation with decreased cadence, that strategies for both stretching and strengthening of the shoulder muscles as well as proper propulsion techniques are essential for rehabilitation.

Soltau et al. (2015) evaluated the symmetry of bilateral propulsion of 80 participants with paraplegia (injury levels not provided) that did not have shoulder pain. The findings suggest there is some asymmetry in propulsion from left to right, which increases with increasing demand on the upper extremity as was found on the 8% grade. The significant differences in joint range of motion (ROM) while statistically significant, were thought not be clinically significant as the differences were almost all less than 5°. The authors conclude that asymmetries in bilateral propulsion are minimal, and that the assumption that propulsion is symmetrical is reasonable for people without shoulder pain or injury that affects strength or ROM.

Jayaraman et al. (2015) examined propulsion kinetics and kinematics of 22 participants who used either the DLOP or semicircular (SC) stroke pattern to determine the influence of an ergonomic metric termed jerk, on shoulder pain. Jerk was measured at the change in direction during the recovery phase. Participants were divided into two groups based on their stroke pattern, and then sub-divided based on presence or absence of shoulder pain. The push phase was identified as being the point when the moment applied to the hand rim was greater than (start) or less than (end) one Nm for a minimum of 10 seconds. The findings suggest that the DLOP results in higher jerk forces than the SC likely due to the increased number of sharp directional changes coupled with increased acceleration/deceleration in the former pattern. The results also identified presence of shoulder pain influenced the jerk forces in that they were lower than in participants without reported shoulder pain. The authors suggested that, based on other non-wheelchair related research on jerk forces the participants with shoulder pain developed a smoother stroke pattern to minimize the impact of pain on propulsion, but they did not negatively affect propulsion effectiveness. The authors also suggested that it would be beneficial to incorporate jerk based metrics into propulsion training/practice in clinical settings.

Russell et al. (2015) observed the kinetics and kinematics differences between two propulsion conditions; self-selected free propulsion and self-selected fast propulsion. The results indicate that there is variability in the effect of increased reaction force magnitude on shoulder net joint moment (NJM) and net joint force (NJF), associated with increased speed of propulsion. The authors suggest that the "magnitude of the shoulder NJM depends on the proximal distal moments created by the NJFs about the centre of mass of the forearm and upper arm segments as well as the adjacent NJM at the elbow." These results suggest that the positon of the upper extremity in relation to the rear wheel has significant effect on the forces influencing the shoulder during fast propulsion. Additionally, the results suggest that many participants use positional strategies to affect the load at the shoulders during fast propulsion. The authors suggest that comparing these two propulsion conditions in clinical practice may prove useful in propulsion training.

Koontz et al. (2012) compared kinetic and temporal propulsion variables between a level smooth tile surface and a wheelchair dynamometer to determine if differences existed. Force data was collected from the push phase of the propulsion cycle only. Their findings suggest that people who push with higher forces and moments and larger push angles can do so on both the dynamometer and the tile surface. However, there were changes noted in the propulsion curve (moment about the wheel hub), with a shift from predominantly bimodal or flat curves on the dynamometer to predominantly unimodal curves on the tile. The authors also conclude that the correlation between propulsion forces on the dynamometer and body weight can provide a means to estimate the peak propulsion forces on the tile surface (83% of variability accounted for by these two variables).. The authors did not comment on the amount of force they used to define higher forces, larger angles, etc.; it is assumed that those participants who would propel with low forces or smaller angles may not be as well correlated between the two surfaces. Since the participants in this study were experienced with wheelchair use (between six and 28 years of experience), it is not clear if the results apply to people with less experience. The authors identify the use of self-selected speeds as another limitation of the study as they differed across conditions. Since there was not a constant speed condition across subject's performances it is questioned if the forces could be different at different speeds, however the authors identify numerous issues with obtaining a constant speed condition especially on the tile floor.

Gil-Agudo et al. (2010) examined differences in shoulder kinetics and kinematics of propelling on a treadmill at 3 km/hr compared to four km/hr. Overall, increasing speed increased shoulder net joint forces and moments, as well as cadence and propulsion angle. Analysis revealed that the predominant force on the shoulder during the push phase was posterior which increased in magnitude as propulsion speed increased and the prominent moment was shoulder flexion. This study also found that during the recovery phase the predominant force was anterior and was greater than the posterior force during the push phase. The authors suggest that study of propulsion should therefore include both the push and the recovery phases; the current tendency is to study only the push phases. It is worth noting that the authors indicated that movements of the trunk, scapula or clavicle were not included in their analysis.

Dallmeijer et al. (1998) explored the effectiveness of force application at the hand rim through the energy output and energy expenditure as an indication of propulsion mechanical efficiency, comparing differences for paraplegic and tetraplegic levels of spinal cord injury. They found that mechanical efficiency was lower in the tetraplegic participant group than the paraplegic participant group. Specifically, differences were noted in the force application to the hand rim which resulted in a significantly lower mechanical efficiency in the participants with tetraplegia. The main differences were a larger lateromedially and reduced frontal plane force application at the hand rim which is consistent with the typical muscular movements available for this group. The authors also found that increasing the intensity (speed) of propulsion resulted in an increased stroke angle for participants in the paraplegic group but a decreased stroke angle in participants in the tetraplegic group. The authors suggest that the effectiveness of force application at the hand rim plays a large role in propulsion mechanical efficiency therefore should be part of propulsion training programs in clinical settings.

Yang and colleagues (2012) investigated the effect of back rest height on propulsion patterns on a level surface and 3° slope. The study suggests that the low backrest (defined as ½ the trunk height as measured from seat base to acrominon) allows for greater shoulder ROM, lower cadence and greater length of stroke as evidenced by differences in start and end hand positions on the rim. Propulsion patterns changed with increased slope, independent of the backrest height. During the 3° slope cadence increased and ROM decreased as did the length

of the stroke. Although the kinetic force impulse on the pushrim was the same for both back support heights, the authors propose that because the hand remained on the rim longer with the low back testing, the force was distributed over a longer time period therefore the effective force was lower. This in combination with lower cadence suggests a lower overall force applied to the pushrim thereby having potential to reduce propulsion injuries. Authors indicate that frequency of pushrim contact has been associated with median nerve injury therefore the height of the back support was important to consider in optimizing propulsion. The authors do note that their participants all had a low-level paraplegia for which a low back support may be appropriate, and that clinical reasoning is required when generalizing these study results to clinical practice. The authors also identified that the use of sling backrests in their study may have influenced the results in relation to propulsion forces due to postural differences between sling and rigid backrests.

Raina et al. (2012a) quantified and compared the scapular kinematics under two different load conditions during wheelchair propulsion on an ergometer. Load conditions were equated to the propulsive resistive forces that would be experienced on flat smooth surface such as tile (no load condition) and on an incline (8% grade for participants with paraplegia and 4% grade for those with tetraplegia). Participants who needed trunk control assistance were strapped to the back support during testing which was not accounted for in the analysis. The findings in this study suggest that on average there are similarities in scapular movement (anterior tilt, downward rotation and protraction) during the push phase of wheelchair propulsion for people with paraplegia and tetraplegia, with a greater ROM used when propelling up an incline. Participants with tetraplegia demonstrated a significantly higher rate of anterior scapular tilting compared to participants with paraplegia. This group also demonstrated a higher rate of change in scapular motion during the push phase of incline propulsion. The authors propose that the significant differences in downward rotation and protraction of the scapula during incline propulsion are associated with higher risk of shoulder impingement due to the reduction of acromial space in this position. While the differences in forces affecting propulsion were accounted for in the two load conditions, there was not an actual change in the level of the surface therefore there was not a change in the body position in relation to the wheelchair as there is in ascending an actual incline. For this reason, it is questioned if the results are fully representative of propulsion up an actual incline.

Qi et al. (2018) assessed the effect of propulsion speed on manual wheelchair user's shoulder muscle coordination. Propulsion at higher speeds required significantly more propulsive muscle activity and energy expenditure. Specifically, the findings showed more muscle activity in the early push phase and in the transition between push and recovery phases at higher speed. The authors suggest that this provides further evidence that faster propulsion places higher demands on muscles to provide joint stabilization during transitions. Therefore, strength training and propulsion techniques that improve transitions may reduce UE demands and improve rehabilitation outcomes. This study was performed using a wheelchair ergometer, which may limit the applicability of results to everyday propulsion.

Cloud et al. (2017) examined the impact of seat dump angle on shoulder and scapular motion during propulsion on a set of custom rollers in individuals whose SCI level ranged from C6-L2. Scapulothoracic internal rotation and downward rotation both increased with increased dump. The implication of these differences towards shoulder health is not clear at this time. Glenohumeral kinematics were also measured but no significant difference was found. The authors suggest that risk of subacromial impingement may therefore be similar regardless of seating condition. Long-term effects were not examined in this study, neither was motion of the

pelvis, forearm, hand, etc. Spine motion was captured and is commented on below in the trunk movement section.

Gil-Agudo et al. (2016) studied shoulder kinetics and ultrasonography before and after a high intensity wheelchair propulsion test in both SCI subjects and healthy controls. Peak shoulder forces and moments increased after the test in almost all directions for both SCI and control groups. Ultrasound parameters did not change before and after the test for individuals with SCI. The control group showed changes in Girometti Index and decreasing long-axis biceps tendon thickness. Tendon thickness did not increase as expected; the authors suggest that the test protocol may have been too short to provoke such changes. The authors also note that some of the differences between groups may indicate beneficial adaptations by manual wheelchair users to generate a longer and smoother stroke, reducing upward shoulder peak force and potentially decreasing risk of shoulder pathology. Worth noting, there were no female subjects tested, which may reduce the applicability of the results to the general population.

Gagnon et al. (2016) examined the association between performance-based manual wheelchair tests (MWPT) and upper extremity strength, trunk strength, and postural stability. Shoulder adductor strength on the weakest side was found to best predict performance during the 20 m maximal velocity test. The authors suggest that the complementary role of shoulder adductors in trunk stability may help to optimize the force applied at the handrim during propulsion. Similarly, shoulder adductor strength and anterior seated reaching are two key predictors of performance on the slalom test, explaining 71.3% of variance. This result emphasizes the high demands on dynamic postural control that are imposed by the numerous trajectory changes of this test. In contrast, handgrip strength best predicted performance on the 6-minute propulsion test. The authors note two reasons that handgrip strength may be principal: it has previously been found to characterize overall UE strength and that handgrip strength is key for the frequent stops and start at high velocity that are incorporated in the 6 min. propulsion test. In summary, MWPT performance is explained by a combination of factors; these results support the relevance of UE and trunk strengthening and dynamic sitting balance training in rehabilitation. However, the authors note that assumptions should not be made regarding causative factors based on their results. Small sample size is also identified as a limitation to the study.

Trunk movement during propulsion

Julien et al. (2014) completed analysis of kinematic data from a previous study for seven people with C5-7 spinal level injuries to describe the trunk and neck movements associated with manual wheelchair propulsion, in relation to speed of propulsion. The study found that forward flexion at the trunk and neck significantly increased during the push phase of propulsion but not during the recovery phase. Increased speed resulted in greater neck and trunk forward flexion. Lateral flexion and axial rotation were variable among participants with no identifiable patterns and did not change significantly with speed. The study concluded that trunk and neck forward flexion play a part in manual wheelchair propulsion for people with tetraplegia, and as such the neck, trunk and core musculature should be considered in conjunction with the upper extremity in future studies of manual wheelchair propulsion particularly around pain and overuse injuries. It is worth noting that there was variability in the identified AIS level with two of seven participants being an AIS C/D.

Rodgers et al. (2000) completed a prospective controlled trial to determine the impact of trunk flexion during propulsion compared to non-flexed trunk propulsion has on the biomechanical and physiological characteristics considered to be precursors to shoulder pain and/or injury. Participants were assigned to the flexion group (FG) based on trunk flexion past 90° from

upright and/or trunk flexion more than 10° during propulsion. All others were assigned to the non-flexion group (NFG). Results indicate that the FG experienced greater shoulder flexion and elbow extension during propulsion than the NFG. The authors suggest this pattern allows greater reliance on trunk excursion to "generate translational forces necessary for wheelchair propulsion." This reliance increased in the fatigued test for both groups but VO2 max did not increase suggesting trunk flexion is used to compensate for muscle fatigue and not to increase aerobic capacity during high demand prolusion.

Triolo et al. (2013) explored the effect of trunk and pelvis stabilization using electrical stimulation on the trunk and hip extensor muscles on the kinetics and kinematics of propulsion. Five of the six participants completed all three propulsion tasks (self-selected walking speed, sprint and incline) with and without muscle stimulation, the results of which were compared as a series of case studies with each participant being their own control. The results were variable, with stimulation significantly decreasing peak resultant handrim forces, improving efficiency and the ability to lean forward in same three of five participants but only during the level self-selected walking speed propulsion; the effect on the other participants were not changed with stimulation. The small number of participants and the effects of stimulation being seen primarily with the same participants and no changes noted in the other participants, suggests that further research is needed to determine if the benefit noted in this study has clinical application.

In addition to shoulder measurements described above, Cloud et al. (2017), measured thoracolumbar spine curvature with respect to seat dump angle. Contrary to their hypothesis, they discovered that participants had significantly less lordosis with increased seat dump angle of 14°. The authors discuss that this may be a result of more hip flexion causing the pelvis to tilt posteriorly, which in turn flattens the lumbar spine. Kyphosis was also measured but was not significantly affected by seat dump angle.

Gagnon et al. (2016) also comment on the role of trunk strength and postural stability in wheelchair propulsion; these results are discussed in the UE section above.

Conclusion

There is level 1b evidence (from two RCT studies by Qi et al. 2019 and Cloud et al. 2017) that seat dump angle affects spinal curvature and scapulothoracic kinematics during wheelchair propulsion; however, the glenohumeral joint may not be affected.

There is level 4 (from one post-test study by Koontz et al. 2012) evidence to suggest that when propulsion force and body weight are correlated, propulsion force on a wheelchair dynamometer correlates to propulsion force on a smooth level surface such as a tile floor.

There is level 2 (from one prospective controlled study by Gil-Agudo et al. 2016, from three post-test studies by Gil-Adugo et al. 2010, Mercer et al. 2006 and VanLandewijck et al. 1994, and one pre-post study; Gil-Agudo et al. 2014. And 2016) evidence that increasing speed/intensity of manual wheelchair propulsion results in an increase in cadence, increases in shoulder forces primarily in a posterior direction and, changes in elbow translation all of which may contribute to the development of shoulder pain. However, no differences in shoulder ultrasound parameters were observed (Gil-Agudo et al. 2016). There is level 1b evidence (from one RCT by Qi et al. 2019) that faster propulsion requires significantly higher propulsive muscle activity and energy expenditure and that faster propulsion requires more muscle activity in the early push phase and in the transitions between push and recovery.

There is level 4 evidence (from one post-test study, Bregman et al. 2009) to suggest that tangential propulsion forces are higher compared to total propulsion forces for people with paraplegic and tetraplegic levels of spinal cord injury as well as for people without a disability.

There is level 4 evidence (from one pre-post study, Russell et al. 2015) that suggests that the forces at the shoulder during fast propulsion are dependent on the forces around the centre of mass at the forearm and upper arm and therefore the position of the upper extremity during the propulsion cycle has a significant effect on shoulder forces.

There is level 4 evidence (from one post-test study, Dallmeijer et al. 1998) to suggest that there are differences in the efficiency of force application at the hand rim between participants with paraplegia and tetraplegia which are a result of differences in available muscle movement/function; force application at the hand rim contributes to a large degree to overall propulsion mechanical efficiency.

There is level 4 evidence (from one post-test study by Mercer et al. 2006) that higher body mass increases shoulder forces and moments, therefore may be associated with a higher risk of propulsion related injuries.

There is level 4 evidence (from one post-test study by Yang et al 2012) that back rest height influences range of motion used for propulsion, cadence and length of stroke used during propulsion.

There is level 4 evidence (from two post-test studies by Yang et al. 2012 and Raina et al. 2012a) that to propel up a slope cadence increases and a greater range of motion is used at the shoulder and scapula.

There is level 1b evidence (from one RCT by Julien et al. 2013) that trunk and neck flexion increase significantly during the push phase of manual wheelchair propulsion for people with tetraplegia.

There is level 2 evidence (one prospective controlled trial, Kim et al. 2015) that indicates the sternocleidomastoid muscle is more active during propulsion in people with thoracic level paraplegia than in non-disabled people.

There is level 4 evidence (from one post-test study by VanLandewijck et al. 1994) to suggest that different muscles are primarily active in the push phase than in the recovery phase and that the onset of the different muscle activity does not coincide with the start of each phase.

There is level 2 evidence (from one cohort study, Jayaraman et al. 2015) to suggest that the change in directions during the recovery phase of propulsion result in high forces at the shoulder, (termed jerk) and varies by the type of stroke pattern used and the presence of shoulder pain.
There is level 4 evidence (from one post-test study by Gil-Agudo et al. 2010) that the predominant shoulder force during the recovery phase is anterior and is greater than the posterior force exhibited in the push phase of propulsion.

There is level 1b evidence (from one RCT, Gil-Agudo et al. 2014) to suggest that both stretching and strengthening of the shoulder muscles and training for optimal wheelchair propulsion techniques are needed as part of rehabilitation.

There is level 4 evidence (from one post-test study, Gagnon et al. 2016) that anterior and lateral flexion trunk strength, anterior seated reaching distance, and shoulder, elbow, and handgrip strength are moderately or strongly correlated with results of performance-based manual wheelchair propulsion tests.

Neck, trunk, scapular, clavicle, elbow, wrist and shoulder kinetics and kinematics singly or cumulatively influence the efficacy of manual wheelchair propulsion and therefore all should be considered in propulsion efficiency as well as in propulsion-related injuries, particularly if propulsion speed or surface slope increases.

The push and recovery phases of propulsion both need to be considered in relation to manual wheelchair propulsion as the kinetics and kinematics differ, and differ between people with paraplegia and tetraplegia, which therefore have implications for propulsion training in the clinical setting.

The following need to be considered in relation to propulsion and back support height; a) effect on propulsion cadence; b) amount of shoulder range of motion used and; c) the length of the push stroke (i.e., length between the start and end position of the hand on the rim).

Wheelchair seating characteristics, such as back support height and seat dump angle, affect body positioning and kinematics of propulsion. Therefore, wheelchair and seating set-up both need to be considered when evaluating kinetics and kinematics of wheelchair

3.1.3 Kinetics and Kinematics of Wheelchair Propulsion on Non-Level Surfaces

The physical environment influences how and where a manual wheelchair is used. Richter et al. (2007b) define cross slope as the slope of a surface perpendicular to one's path of travel. Sidewalks, pathways and roads have some degree of cross slope to drain water.

This subsection reviews research articles that examined specifically the kinetics and/or kinematic properties of propulsion on non-level surfaces. Several of the articles used the test items from some of the formal wheelchair skills programs to frame the study but did not report on outcomes of the programs therefore were included in this section as opposed to the wheelchair skills subsection. The non-level surfaces explored in these studies included wheelies, curb ascent, ramps, soft surfaces such as carpet and grass, and cross slopes.

 Table 3. Kinetics and Kinematics of Wheelchair Propulsion on Non-Level Surfaces

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Martin-Lemoyne et al. 2016 Canada RCT PEDro=5 N=10	 Population: Mean age= 36.0 yr; Gender: males=6, females=4; Level of injury range: C6-T11; Mean time since injury: 11.9 yr. Intervention: Mechanical load and muscular demands were measured for manual wheelchair (MWC) users using a SMARTWheel installe don participant's own w/c, an Optotrack motion analysis system, and surface electromyography on the shoulrder muscles. Participants propelled up a ramp with and without a mobility assistance dog (AD_{Mob}). The course had a 4 metre long, 8.5° ramp covered with a thin layer of asphalt. Each intervention was completed 3 times by each participant with rest periods between as needed Outcome Measures: Spatiotemporal parameters: push phase, recovery phase, propulsion cycle, contact angle, speed; Pushrim kinetic: total force (Ftot), tangential force (Ftan), mechanical effective force (MEF); Shoulder moments: flexion(flex)-extension(ext), adduction (add)-abduction (abd), internal rotation (IR)-external rotation (ER); Muscular utilization ratio (MUR); Perception of upper limb effort as measured on a 10 point visual analog scale 	 The use of an AD_{Mob} allows manual wheelchair users to ascend the ramp significantly faster while requiring significantly less upper limb efforts. Traction significantly increased (p=0.037) wheelchair speed with the AD_{Mob} compared with the same task without the AD_{Mob}. A significantly shorter (p=0.013) push phase and significantly longer (p=0.028) recovery phase when using the AD_{Mob} compared to without. F_{tot} and F_{tan} were significantly reduced with the use of the AD_{Mob} compared to without (p=0.005, and p=0.002, respectively). The maximum shoulder flexion (p=0.047), add-abd (p=0.017), and IR-ER (p=0.028) net joint moments were significantly reduced with the traction provided by an AD_{Mob}. MUR was significantly reduced for all tested muscles (p≤0.022). The perception of upper limb effort was significantly reduced (p=0.005) when performing the experimental task with traction provided by the AD_{Mob}.

			The second second
	Population: Mean age: 40.8 yr; Gender:	1.	The average durations of the push
	males=17, females=1; Level of injury:		phase were similar for all tested slopes
	cervical=1, thoracic=17: Level of severity:		(p=0.267), whereas the average
	$\Delta IS \Delta = 12 \Delta IS B = 3 \Delta IS C = 2 \Delta IS D = 1$		duration of the recovery phase
	All $A = 12$, All $D = 3$, All $C = 2$, All $D = 1$, Mean time since injung 0.2 yr		dealined as the along become steeper
	Mean time since injury: 8.2 yr.		declined as the slope become steeper
	Intervention: Participants propelled their		(p=0.043).
	manual wheelchair (MWC) at a self-	2.	The total duration significantly
	selected natural speed on a treadmill at		decreased as the slope became
	different slopes (0, 2,7, 3,6, 4,8, and 7,1		steeper, except for during the 2.7° to
	degrees) which reflected an increase from		3.6° where the slope increment
	one unit in height to 20, 16, 12 and 8 units		remained similar (p<0.001)
	of length respectively. Each angle had two	2	At the trunk oll minimum movimum
	trials la sting 4 min with a Omain mart	5.	At the truth, all minimum, maximum,
	trials lasting 1 min with a 2 min rest		and excursion movement amplitudes
	between tests.		significantly increased as the slope
	Outcome Measures: The last 10		became stepper (p<0.0125), except for
	consecutive complete propulsion cycles		minimum and maximum values during
	were used to calculate outcomes Temporal		the 2.7° to 3.6° slope increment that
	parameters (push phase duration		remained similar (p>0.0125) At the
	Perovery phase duration. Total cycle		7 1° slope the greatest maximum
	duration. Trunk and shoulder movement		forward trunk flavian (60.0%) and the
			Iorward trunk nexton (60.9) and the
	kinematics (minimum, maximum, excursion		greatest forward trunk excursion
Gagnon et al. 2015	movement amplitudes), Shoulder kinetics		(22.4°) was reached.
Canada	(flexion/extension, adduction/abduction,	4.	The mean and maximum shoulder
Bro Boot	internal/external rotation moments), Peak		flexion moments significantly improved
	and mean muscular utilization ratio (MUR)		as the slope increased (p<0.0125),
N=18	and the indicator of muscle work (IMW) for		except for the 3.6° to 4.8° and 4.8° to
	the anterior deltoid. Posterior deltoid		7 1° slope increments
	Rectoralis major clavicular fibers. Stornal	Б	The mean adduction moments only
	fibera Significance was informed at	5.	significantly improved on the along
	inders. Significance was interred at		significantly improved as the slope
	p≤0.0125.		increased between 0° and 2.7°
			(p<0.001), whereas the peak mean
			value only significantly improved as
			the slope increased between 0° to 2.7°
			(p<0.001), 3.6° to 4.8° $(p=0.002)$, and
			4.8° to 7.1° (n=0.002) slope
			increments
		e	The mean and maximum internal
		0.	
			rotation moments significantly
			increased as the slope became
			steeper (p<0.0125), except for the 3.6°
			to 4.8° slope increment.
		7.	The mean and maximum MURs and
			their indicator of muscle work value
			significantly increased (ANO)/A
			r_{2} 0.01) as the slope became steeper
			protocity as the slope became sleeper
			except for the posterior deitoid and
			that remained comparable between
		1	2.7° to 3.6° slope increment.

		1	
	Population: Mean age: 40.8 yr; Gender:	1.	The recovery phase at 0° was 54 to
	males=17, females=1; Level of injury:		70% longer than for the other different
	cervical=1, thoracic=17; Injury severity: AIS		slopes (recovery phase at:
	A=12, AIS B=3, AIS C=2, AIS D=1; Mean		0°=0.59±0.22, 2.7°=0.27±0.10,
	time since injury: 8.2 yr.		3.6°=0.26±0.09, 4.8°=0.22±.0.08,
	Intervention: Participants propelled their		7.1°=0.18±0.05; p<0.001).
	manual wheelchair (MWC) at a self-	2.	The final contact angle was similar
	selected natural speed on a level treadmill		across all slopes except for the 0°
	and then at randomly assigned slopes (0°,		slope, which was significantly lower
	2. 7°, 3.6°, 4.8°, and 7°) Each angle had		than all other slopes (final contact
	two trials lasting 1min with a 2min rest		angle at: 0°=45.97±9.04, (p≤.001)
	between trials. Self-selected speeds were		2.7°=52.04±9.20, 3.6°=53.46±10.36,
	determined by timing propulsion over a		4.8°=57.92±11.82, 7.1°=65.54±9.82,).
	20m tile floor three times with a 2min rest	3.	Total contact angle remained greater
	between trials		during the level surface than all other
	Outcome Measures: Data was divided		slopes ((p≤.005) with the slopes
	into the push phase (hand in contact with		presenting similar total contact angles
	rim) and the recovery phase (hand not in		(p=0.14, p=0.24).
	contact with rim). Data was collected using	4.	The greatest mean difference of total
	the SMARTWheel on the non-dominant		force and tangential force was found
Compan at al. 2014	side. The last 10 consecutive complete		between 0° and 2.7° slopes compared
Gagnon et al. 2014	propulsion cycles for each trial were used		with the differences observed between
Callaua Dro Doot	to calculate means for: 1) duration of push		the other consecutive slopes (mean
	and recovery phases and propulsion cycle		total force at: 0°=39.56±11.15,
IN=10	(both push and recovery phases), 2)		2.7°=76.25±19.55, 3.6°=81.49±18.86,
	contact angles, 3) total force, 4) tangential		4.8°=95.49±21.16, 7.1°=119.21±18.42;
	force, 5) mechanical effective force (MEF),		p<0.001. mean tangential force at:
	perceived effort. Significance was		0°=24.52±8.84, 2.7°=48.04±13.08,
	inferred at p<0.001.		3.6°=52.25±14.27, 4.8°=58.00±14.69,
			7.1°=68.05±16.61; p<0.001).
		5.	The MEF values were similar across
			all slopes located at approximately
			80% of the propulsion phase (MEF
			values at: 0°=0.43±0.09,
			2.7°=0.44±0.06, 3.6°=0.45±0.10,
			4.8°=0.42±0.06, 7.1°=0.38±0.10;
			p>0.05).
		6.	The perceived effort increased as
			slope angle increased, with the 0°
			slope having the lowest perceived
			effort and the 7.1° slope showing the
			greatest perceived effort (perceived
			effort at: 0°=1.18±1.10,
			2.7°=3.78±2.83, 3.6°=4.06±2.69,
			4.8°=5.27±2.80, 7.1°=6.86±2.68; no p-
			value provided).

Pierret et al. 2014 France Pre-Post N=25	Population: Mean age: 38.9 yr; Gender: males=25, females=0; Level of injury: T3- L4; Mean time since injury: 10.6 yr. Intervention: Participants performed two tests: 1) a test involving sub-maximal exertion on an arm ergocycle on the first day to estimate peak oxygen uptake up to 85% maximum heart rate, and 2) eight laps of a 50 m propulsion track with a cross slope (Cs) of 0, 2, 8, and 12 % each at two different velocities (one self-selected, one imposed rate). The intersession interval between tests was at least 2 days. Outcome Measures: Heart rate (HR), absolute cardiac cost (ACC), relative cardiac cost (RCC), peak oxygen uptake (VO ₂), energetic cost per meter travelled and per kg weight (ECmkg), relative energetic cost (REC), Rating of Perceived Exertion (RPE) scale.	 1. 2. 3. 4. 5. 	5 participants were unable to complete the last 50 m lap under all test conditions. No significant differences were noted in HR or VO ₂ for the 0% and 2% Cs. The HR, ACC, and RCC are all significantly altered by the velocity conditions (F>95; p<0.001) and, for each velocity, by the three different Cs (p<0.001).ACC also increased by user weight (p<0.001), age (p<0.001), injury level (p<0.001) and VO2 max decrease (p<0.001). The VO ₂ , ECmkg and the REC values (energetic strain) are all significantly altered by the velocity conditions (p<0.005) and by the Cs for each velocity (p<0.001). The energetic strain increases when age (p<0.001) or body mass index (p<0.001) increase or when physical activity (p<0.001), injury level (p<0.001) or VO2Max (p<0.001) decrease. The RPE results remain unaltered by the velocity (p>0.04), but the Cs increase significantly the RPE
Marchiori et al. 2014 Canada Post Test N=11	Population: Mean age: 31.8yr; Gender: males=9, females=2. Intervention: Participants were instructed to approach an obstacle 8 cm high at a comfortable speed, then lift the caster wheels off then ground just before it, without stopping, and ascend it, using their own wheelchair. The ascent was divided into three phases based on the angle formed between the wheelchair frame and the ground: caster pop (P1), rear-wheel ascent (P2), and post ascent (P3). Participants used their own manual wheelchair. Outcome Measures: SMARTWheel and eight camera video system to capture 3D joint power, 3D angle between the wrist, shoulder and elbow joint moments and angular joint velocity (moment).	1. 2. 3.	 The highest moment and peak net moment of the three joints (i.e., shoulder, elbow, and wrist) was found during P2 in flexion. Forward trunk flexion started early in the caster pop phase According to the 3D angle: The wrist was more in a stabilizing configuration during P1 and P2, and generated energy during P1. The shoulder joint was in a stabilizing configuration during obstacle ascent and generated energy during P3. The elbow was in a stabilizing configuration during P3, absorbing energy during P1 and P2.

	Population: Mean age: 38.0 vr. Gender:	1	All participants ascended 4 and 8 cm
	males-14 females-1: Level of Injune	'.	curbe: 80% (n=15) were able to
	TO 1 TA 1 TE 1 TE 2 TO 2 TO 0		12 or 00% (II=13) were able to
	12=1, 14=1, 10=1, 10=2, 17=2, 10=8, 10=2, 17=2, 10=8, 10=1	_	
	110=3, 111=2, 112=2; Level of severity"	2.	Curb approach speeds differed
	AIS A=13, AIS B=1, AIS C=1; Mean time		significantly (p<0.0001) with speeds
	since injury: 9.5 yr. All MWU >4 hr/day, and		progressively increasing as the curb
	self-reported independence with curb	_	height increased.
	ascents of ≤12 cm with no shoulder pain.	3.	Curb height did not affect total
	Intervention: Participants were asked to		duration (p=0.7), the duration of the
	complete three curb ascend tasks (curb		caster pop phase (p=0.849) or the
	height=4cm, 8cm, and 12cm) at a self-		rear wheel ascent (p=0.077).
	selected speed in their own w/c with 3m	4.	In the sagittal plane of motion most
	approach.		movement differences were noted.
	Outcome Measures: Trunk and upper		maximum trunk flexion along with the
	extremity kinematics and shoulder, elbow		total excursion of trunk flexion,
	and wrist net joint moments using: a motion		maximum shoulder flexion, and
	analysis system (Optotrak) with 23 skin-		greater flexion, extension and
	fixed markers and four markers attached to		movement excursion in the plane of
	w/c frame: two instrumented rear wheels		motion at the elbow, all progressively
	(SMART wheels) and: surface		increased as the height of the curb
	electromyography. Measures compared at		was increased from 4cm to 8 cm
	caster pop, rear-wheel ascent and post		(p≤0.001, p≤0.0001, p≤0.004
	ascent phases to determine related effect		respectively) and then from 8cm to
	of curb height		12 cm (p < 0.001 p = 0.008 p < 0.004
			respectively) However the excursion
			of shoulder movement in the sadittal
			plane only improved significantly
Lalumiere et al. 2013a			when the curb height was increased
Canada			from 4 cm to 8 cm ($p<0.0001$) No
Post-Test			movement difference was confirmed
N=15			at the wrist across the various curb
N=15			beights $(n > 0.05)$
		5	Compared to the 4 am ourb, all mean
		5.	and pack total pat momenta produced
			and peak total het moments produced
			at the shoulder, endow and when
			significantly increased when
			ascending the 6 cm ($p \le 0.0001$) of 12
		~	Cill curb ($p \ge 0.01$).
		ю.	Compared to the 8cm high curb, only
			the mean shoulder (p=0.001) as well
			as the peak and mean elbow total net
			joint moments ($p \ge 0.009$) further
			Increased to a significant extent when
		-	ascending the 12cm high curb.
		1.	Compared to the height of 4 cm, the
			peak rate of rise (ROR) values of the
			total shoulder net joint moment and of
			the shoulder flexion net joint moment
			were found to be significantly greater
			when ascending a height of 8 or 12
			cm (p≤0.005). However, these values
			were similar when ascending an 8cm
			or 12 cm curb (p≥0.299).
		8.	All mean (p≤0.031) and peak
			(p≤0.039) muscular utilization ratio
			(MUR) values for the upper extremity
			muscles assessed differed
			significantly across all heights.

Lalumiere et al. 2013b Canada Post-Test N=16	 Population: Mean age: 38.1yr; Gender: males=15, females=1; Level of injury: T=15 (T2-12), C=1 (C7); Mean time since injury: 9.2 yr. Intervention: Compare the effects of four distinct rolling resistances (RRs) on the intensity of handrim kinetic measures on the non-dominant upper-limb (U/L) as well as symmetry (i.e., dominant versus on-dominant) of forces during the execution of wheelies among manual wheelchair users with SCI. Four wheelies per four randomized RRs including: (1) natural surface of painted high-grade smooth composite board (NAT), (2) 5-cm thick urethane soft yellow foam (LOW), (3) 5-cm medium viscoelastic pink memory foam (MOD), and (4) two 5-cm high wooden blocks with rear wheels completely blocked (HIGH). Outcome Measures: Handrim kinetics: resultant force (Ftot), medial force (Fz) and tangential component of the resultant force (Ftg) measured using two instrumented wheels (Smart Wheels) during four phases of the wheelie: preparation, take-off, balance, and landing as measured by the angle between the w/c frame and ground surface. Motion analysis system used to synchronize data from instrumented wheels; symmetry index intensity measured to verify if forces were similar bilaterably. 	1. 2. 3. 4.	No significant differences in duration of each phase of the wheelie, except for the wheels blocked (High) for take-off and landing which were longer than all other surfaces. The mean and maximal Ftot were greater (p=0.001009) during the HIGH RR compared to the other RRs. During the preparation phase, Ftg patterns showed a forward force application compared to a quick backward force with all other RRs. The maximal Fz was similar across all RRs. The mean and max Ftot were greater during the take-off phase of performing a wheelie, compared with the other phases (preparation, balance, and landing phases) for all RRs. The mean and max Ftg were greater also during the take-off phase compared with all other phase regardless of RR. The mean Fz was similar during the balance and landing phases, however was significantly greater during the take-off phase compared to the preparation phase.
Nagy et al. 2012 USA Post-Test N=23	Population: Mean age: 38 yr; Gender: males=20, females=3; Level of injury: tetraplegia=5 (C6-T1), paraplegia=19 (T4- L3); Mean time since injury: 14.8 yr. Intervention: All participants used their own ultra-lightweight manual wheelchair and seating. Each had one practice and then one test trial of a series of eight of the following skills from the Wheelchair Skills Test: 10m tile surface, 10m of carpet surface, soft surface, 5° and 10° ramps, 2 cm, 5 cm and 15 cm curbs. Outcome Measures: SmartWheel used to analyze push rim forces exerted during propulsion. Peak force for the first four skills was calculated from the entire performance; peak for the remaining skill were taken from the pushes that allowed successful completion. Mean peak force comparisons were completed using paired t-test for each skill to the 10 m tile skill.	1.	The mean peak pushrim forces were as follows for the skills: 10 m tile=101 N, 10 m carpet=103 N, soft surface=148 N, 5° ramp=138 N, 10° ramp=157 N, 2cm curb=119 N, 5 cm curb=155 N, 15 cm curb=232 N. **Only 6 szzubjects completed the 15cm curb). Comparison between mean peak forces of each skill compared to 10 m tile were all statistically significant (p=0.0001267) except the 10m carpet.

Morrow et al. 2010 USA Post-Test N=12	Population: Mean age: 43 yr; Gender: males=11, females=1; Injury etiology: SCI=11, spinda bifida=1; Duration of manual w/c use: 18 yr. Intervention: Five trials, with rest between, propelling at a self-selected speed for each condition in the following order: 1) push phase of level propulsion, 2) push phase of ramp propulsion (1:12 incline), 3) push phase of start, 4) negative acceleration phase of stop, 5) weight relief maneuver (push up and hold for 3 sec). Outcome Measures: Two instrumented rear wheels (SmartWheels) on participants on manual wheelchair to capture force data at handrim; Motion analysis system (Real- time Eagle) with 15 markers on the trunk and right upper extremity and three each on the rear wheels to capture moments; Force of direction was defined as anterior (+) and posterior (-) of the x axis, medial (+) and lateral (-) of the y axis and superior (+) and inferior (-) of the z axis. Moment direction was defined as flexion or extension about the trunk z axis, elevation abduction and elevation adduction about the humerus x axis and internal and external rotation about the humerus z axis.	1. 2. 3.	There was a significant main effect of condition for the shoulder intersegmental forces in 4 of 6 force directions: anterior (p=0.001), posterior (p<0.001), medial (p=0.003), and superior (p<0.001). Post hoc analysis of the intersegmental shoulder forces indicated that: 1) in ramp condition the anterior force was significantly higher than level propulsion, weight relief , start and stop conditions, 2) posterior force of the ramp and weight relief conditions were significantly higher than level, start and stop conditions, 3) weight relief medial force was significantly higher than level, start and stop conditions. There was a significant main effect for the shoulder intersegmental moments for three of six moment directions: extension (p<0.001), adduction (p=0.009), and external rotation (p=0.004). Post hoc analysis of the intersegmental shoulder moments indicated that: 1) extension moment for weight relief was equal to start but significantly greater than level, ramp and stop conditions, 2) Adduction moment for ramp was significantly higher than level, ramp and stop conditions, 2) Adduction moment for ramp was significantly higher than level, ramp and stop conditions, 2) Adduction moment for ramp was significantly higher that level condition, 3) external rotation moment of ramp and start were significantly greater that in the level condition, 4) abduction (p=0.092) or internal rotation (p=0.102). There was no main effect of condition for
			flexion.

Hurd et al. 2008 USA Post-Test N=12	Population: Mean age: 43.6 yr; Gender: males=11, females=1; Injury etiology: SCI=11, spina bifida=1; Level of injury range: T4-L10; Duration of w/c use: 18 yr. Intervention: Evaluated U/L symmetry during self-selected propulsion rates across eight different terrain conditions consisting of propelling straight forward in laboratory, outdoor community and indoor community. The outdoor community was a single continuous 500m concrete sidewalk that progressed across four conditions in this order; 1) 2° right side lower cross slope; 2) smooth level surface; 3) level aggregate (textured) surface; 4) 3° ramp (1:19 rise to run) smooth surface. Indoor community =1) 10 m level, low pile carpet and 2) 4.8° ramp (1:12 rise to run) with low pile carpet. Laboratory= 1) 10 m smooth level tile surface and 2) dynamometer with level surface. 1 trial completed for outdoor community and 1 st laboratory items and; 1 30 trial on dynamometer. Outcome Measures: Three push cycles using two instrumented rear wheels (Smart Wheels) were averaged to capture propulsion timing, effort and force using variables of moment, total force, tangential force, fractional effective force, time-to- peak propulsion moment, average work in joules, contact (length of push cycle) and instantaneous power. Symmetry index was used to determine symmetry of U/L propulsion (perfect symmetry=0 used for commarison)	 1. 2. 3. 4. 5. 6. 	Symmetry indexes were significantly different within each condition across all variables. Between conditions, symmetry variables were also significantly different (propulsion moment, p<0.001; total force, p=0.004; tangential force p<0.001; fractional effective force, p<0.001; time-to-peak propulsion moment, p=0.001; work, p<0.001) Comparing the within lab conditions (tile floor versus dynamometer) indicated no differences in symmetry indices for any variable Comparing the lab versus indoor conditions indicated no significant differences in symmetry indices for any variable. Comparing lab versus outdoor conditions resulted in significant differences in symmetry indices for all variables with outdoor being greater than lab except for time-to-peak moment (p=0.188) No patterns of dominant versus non- dominant upper limb contribution to propulsion were noted.
Richter et al. 2007b USA Post-Test N=26	 Population: Mean age: 36 yr; Gender: males=19, females=7; Level of injury: paraplegia=24, spina bifida=2; Chronicity: chronic. Intervention: Propulsion of personal wheelchair on a treadmill set at level, 3° and 6° inclines. Outcome Measures: Speed, Force, Torque and loading rate, Cadence, Push angle, Power output, Push distance. 	 1. 2. 3. 4. 	All kinematic factors increased significantly when the incline increased from level to 6°: peak handrim force, 1.4 increase; loading rate, 1.3 increase; axial moment, 1.8 increase (p=0.00). Push angle and cadence were not affected. As the incline increased, distance traveled forward per push dropped (3°, p=0.034; 6°, p=0.00). Subjects utilized approximately 80 and 100 more pushes/km for the 3° and 6° inclines. Coast time decreased from 0.43 sec (level) to 0.35 sec (6° incline). Power output for the downhill wheel increased 1.6 and 2.3 times more than level for 3° and 6° (p=0.00).

Discussion

Richter et al. (2007b) investigated the effect of cross slope on wheelchair handrim biomechanics. The data from this study indicates that more pushes are required to cover the same distance when on a cross slope and that the power required increased by a factor of 2.3

on a six-degree cross slope. Users must push harder on the downhill handrim and this increased loading may result in overuse injuries.

LaLumiere et al. (2013b) compared the effects of different rolling resistances on hand rim kinetics during manual wheelchair wheelies performed by people with a spinal cord injury (T12-C7) who had no history of shoulder pain. The rolling resistance (RR) was created by the surface on which the wheelie was performed; painted, high grade smooth composition board (NAT); five cm thick urethane soft yellow foam (LOW), 5-cm medium viscoelastic pink memory foam (MOD), and two five-cm high wooden blocks with rear wheels completely blocked (HIGH). The wheelie was analyzed in four phases; preparation, take-off, balance and, landing. Findings indicate that the HIGH RR was the least desirable surface for performing wheelies. The HIGH RR produced the greatest mean and total hand rim forces at all phases, showed a forward force application to lift the casters off the ground whereas all others used a quick backward force. The authors also found that the take-off phase mean and maximum resultant forces and mean and maximum of the tangential components of the resultant forces were greater than all other phases regardless of the RR. The authors conclude that completing wheelies with the rear wheels blocked requires different motor learning strategies than on the other surfaces. Symmetry between dominant and non-dominant upper extremities was also evaluated in this study, with the findings suggesting that exertion forces are symmetrical in each phase. However, during the balance phase, the direction of the exerted forces differed on the NAT and LOW surfaces with the different direction oscillating between the dominant and non-dominant upper extremities to maintain balance. The authors reported looking to another study (Boninger et al 1999) in which the same propulsion forces were used to compare propulsion forces to the forces required to complete a wheelie on the NAT surface. From this comparison, they conclude that the forces are similar between these two skills, and that given the frequency of propulsion compared to performing wheelies, wheelies may represent a decreased risk to UL's versus propulsion. However, the authors did not expand on this comparison so it is questioned that if the intensity of these two skills are the same, would an increase in the frequency of wheelies result in a similar risk exposure as propulsion.

LaLumiere et al. (2012a) compared movement strategies (kinematics), mechanical loads (kinetics) and relative muscle demands on the non-dominant side while 15 people with paraplegia ascended curbs of four, eight and 12 cm heights; participants propelled a threemetre approach at a self-selected speed. The authors hypothesized that the mechanical loads and muscular demands, especially at the shoulder would increase as curb height increased. The curb ascent was divided into the phases of caster pop-up, rear wheel ascent and post ascent phases. The authors report that the greatest net joint moment for all curb heights was shoulder flexion, closely followed by shoulder internal rotation and elbow flexion, which were corroborated by their EMG results. This study found limited elbow extension effort with this skill of curb ascension; in fact, the elbow flexors (long head of biceps) were used to succeed with ascending curbs. The muscle utilization ratio (MUR) at the pectoralis major, anterior deltoid and biceps brachii indicate these muscles contribute highly to these primary moments involved in ascending curbs. The moment demands placed on the shoulder and elbow joints progressively increased from a four to 12 cm curb, specifically 2.2 times for shoulder flexion and internal rotation, 2.8 times for shoulder adduction and 1.8 times for elbow flexion. Similarly, the muscle demands as measured by EMG, increased as the curb height progressively increased. Considering the substantial shoulder and elbow demands with this task found in this study, the authors suggest that it is plausible that a decreased strength-generating capability at the shoulder flexors/adductors or at the elbow flexors could increase the mechanical demand and increase risk of musculoskeletal injury. The authors also found that forward trunk flexion increased as the curb height increased, suggesting that the forward momentum created by

flexing the trunk and head in the direction of movement assisted in the second phase of rear wheels ascending the curb. The authors do report that the possible contributions of using forward trunk flexion were not fully examined in this study but they do propose there is benefit to include trunk flexion strategies in curb ascent training to augment the increasing demands on the shoulders and elbows as the curb height increases. Based on this study's findings, the authors highlight clinical implications for injury prevention focused on 1) the individual and optimizing strength at shoulder flexors, shoulder adductors, and elbow flexor muscles, and determining the ability to use forward trunk flexion and 2) the environment by continuing to advocate for barrier free environments to decrease upper extremity risk exposure.

Marchiori et al. (2014) examined the joint angle and velocity during obstacle ascent in a manual wheelchair by 11 people up an 8 cm curb. Findings suggest increases in peak moments in the wrist, elbow and shoulders compared to propulsion, although their study did not measure level propulsion. Forward trunk flexion during the caster pop phase was stated to be supported by other study results, suggesting forward trunk flexion during this phase may reduce upper extremity strain, but this study did not provide supporting data.

Nagy et al. 2012 examined the pushrim forces during various advanced manual wheelchair skills compared to forces exerted during propulsion over a 10-metre tile surface. Advanced skills tested were from the Wheelchair Skills Test developed at Dalhousie University, which included; 10 meters of carpet, a soft surface, 5° and 10° ramps and 2 cm, 5 cm, and 15 cm curbs. The primary finding that the more advanced the skill the more force required. The authors note an increase in forces ranging from 18 to 130% but do not provide details of calculations. Discussion in this article focuses on the need to consider the forces being exerted during advanced wheelchair skills and the need to preserve upper extremity integrity through minimizing repetitive forces. However, the authors did not note if the participants were experienced with basic or advanced wheelchair skills nor the potential influence of skill experience on the forces exerted during the skills measured. The authors also did not discuss the implications or the need to balance minimizing the impact of pushrim forces with maintaining an active lifestyle or to the impact of wheelchair set-up/technique on the force.

Hurd et al. (2008) examined the symmetry of propulsion across a variety of terrains, for people with paraplegia (11 SCI, T4-L10, and one spina bifida). Findings indicated that propulsion asymmetries exist for all conditions with the magnitude of the difference being affected by the environment/terrain. Outdoor condition had the greatest magnitude of propulsion asymmetry. No differences were found in the magnitude between laboratory (tile floor and dynamometer) and indoor community conditions. The authors note that their results could not explain these differences, but they question the effect of fatigue on the results as the outdoor conditions were completed in one continuous pathway to simulate actual outdoor conditions, whereas the others were single testing conditions with rests in between. Dominance did not appear to have a role as no patterns of dominant versus non-dominant upper limb use during propulsion was detected for any condition. For these reasons the authors caution the use of single or averaged bilateral data for propulsion-based studies. The authors also highlight that these results, despite the limitations, underscore the need to complete propulsion evaluations and training in the person's own natural environments to fully understand propulsion kinetics and kinematics.

Morrow et al (2010) examined intersegmental shoulder forces and moments during everyday propulsion activities for daily life and mobility. Findings indicated that forces and moments vary significantly across the conditions used to simulate daily life and mobility activities. Not surprisingly, the weight relief condition (push up and hold for three seconds) produced significantly higher shoulder forces than the level, start and stop propulsion conditions. The

magnitude of forces at the shoulder was highest for the weight relief followed by the ramp condition in most directions of force. The weight relief maneuver resulted in a peak superior direct force two times greater than the magnitude of ramp propulsion and three times the magnitude of level propulsion. The authors suggest that the findings indicate that the weight relief maneuver and propelling up a ramp are very high loading activities compared to level propulsion and as such the frequency of these high loading activities needs to be considered as part of maintaining shoulder health. Regarding shoulder moments, most shoulder moments during ramp propulsion and start conditions were equivalent but higher than level propulsion. Extension and abduction moments were higher in ramp propulsion, weight relief and start conditions compared to level propulsion. The authors suggest these findings are indicative of weight relief, ramp propulsion and start conditions placing the largest estimated loads on the shoulder during propulsion.

Gagnon et al. (2014) examined the spatiotemporal propulsion cycle and push rim kinetics of the non-dominant hand during manual wheelchair propulsion in 18 people with spinal cord injury on a level surface and up four different slopes on a wheelchair treadmill. The slopes chosen corresponds to a 1:20, 1:16, 1:12 and 1:8 ratio of vertical height to horizontal length of the slope, similar to standards for ramps. Overall, they found that the push phase remained relatively the same on all slopes however, the recovery phase became shorter as the slope increased, with the recovery phase at the level surface being significantly longer than the slopes (54% - 70%). Therefore, as the authors suggest, the pushing frequency increases to offset the gravitational effect of the slope on the wheelchair. The initial contact on the rim moved forward with increasing slope and contact angle remained similar on the slopes equal to or greater than 3.6°. The authors question if the contact angle results are related to the forward flexion of the trunk during propulsion on slopes which was explored in their 2015 study (see below). Forces applied to the push rim increased as the slope increased, 200% at the greatest slope, however no similarities between the slopes were found which, the authors suggest, indicates the relationship between slope and push force is not linear. The authors suggest that these findings support the need for ramps with smaller slopes (2.7° or 3.6° which correspond to 1:20 and 1:16 respectively) as these slopes require similar effort and the greater slopes of 1:12 (4.8°) require greater effort, use greater forces, require more frequent push phases therefore have greater implications for shoulder integrity maintenance.

Gagnon et al. (2015) also examined the kinematic changes of the trunk and non-dominant shoulder in 18 people with spinal cord injury during manual propulsion up five different slopes (0°, 2.7°, 3.6°, 4.8° & 7.1) at a self-selected speed. All participants could maintain their self-selected propulsion speed of 1.17±0.18 m/s on the level surface and the 2.7° slope but only 88.9%, 77.8% and 55.6% were able to maintain it on the 3.6°, 4.8° and 7.1° slopes respectively. Forward trunk flexion, peak shoulder flexion, and shoulder mechanical and muscular efforts all increased as the slope increased. The authors suggest that the forward trunk flexion in conjunction with the forward trunk excursion may assist in moving the centre of mass anteriorly to prevent backward tipping as the slope increased. The authors also suggest that the increase in shoulder flexion but comparable flexion excursion across all slopes may be related to the need to accommodate at the shoulder for the forward trunk flexion. Additionally, the muscular and mechanical demands of the shoulder, particularly of the posterior deltoid muscle at the end of the push phase, also increased as the slope increased. The authors suggest that these finding support the clinical practice of high-intensity, short duration strength training for the upper extremity, especially the shoulders, to reduce the risk of shoulder integrity issues.

Martin-Lemoyne et al. (2016) also examined the mechanical load and muscular demands of the shoulder when ascending a 4-metre-long, 8.5° ramp; however the focus was on comparing

ramp ascent with the assistance of a mobility assistance dog (AD_{Mob}) and without assistance. They found that with the AD_{Mob} the ascent was 38.3%faster, the push phase was 45.4% faster and the recovery phase was 38.6% longer. Participants also demonstrated significantly lower shoulder net movements (flexion, adduction and internal rotation) and lower upper limb exertion at the lower deltoid, biceps, triceps and pectoralis major muscles. Overall the authors noted reduced mechanical and muscular demands and participant perceived upper limb effort was 62.8% lower when using the AD_{Mob} . The authors suggest that more research is required to explore the effects of this type of intervention on the dog, as well as to explore potential challenges that may arise in daily life with a dog.

Pierret et al. 2014 examined the cardiorespiratory effect and perceived strain experienced by 25 men who sustained a thoracic or lumbar spinal cord injury during manual wheelchair propulsion on cross slopes of zero, two, eight and 12%. They found that cross slopes of zero percent and two percent did not differ in cardiorespiratory and subjective strains but that the 8% cross slope was found to have significant effects on cardiorespiratory strain and perceived strain but all participants were able to manage; not all participants were able to manage the 12% cross slope.

Conclusion

There is level 4 evidence (from one post-test study; Richter et al. 2007b) that wheeling cross slope results in increased loading on users' arms and may lead to overuse injuries.

There is level 4 (from one post-test study by Nagy et al. 2012) evidence that advanced wheelchair skills require greater peak forces at the hand rim, however there is level 4 (from one post-test study by LaLumiere et al. 2013b) evidence that wheelies require a mean peak hand rim force similar to that of wheelchair propulsion.

There is level 4 (from one post-test study by LaLumiere et al 2013a) evidence that ascending curbs of increasing height increases the mechanical and muscular demands at the shoulder and elbow joints placing these joints at risk of injury especially if adequate strength in the associated muscles is not present.

There is level 4 (from one post-test study by Hurd et al. (2008)) evidence upper limb asymmetries exist in manual wheelchair propulsion with greater asymmetry in outdoor versus laboratory (tile floor and dynamometer) conditions.

There is level 4 (one post-test study by Morrow et al. 2010) evidence that the daily life and mobility activities of weight relief, ramp propulsion and the start phase of propulsion place the larger estimated loads on the shoulder and use greater shoulder abduction and extension moments compared to level propulsion.

There is level 2 (from one lower RCT study by Martin-Lemoyne et al. 2017) evidence that mechanical and muscular demands as well as perceived upper limb effort are significantly reduced when ascending a steep ramp with the assistance of a mobility assistance dog compared to without.

There is level 4 evidence (from one pre-post study; Pierret et al. 2014) that suggests the physiological demands of propulsion increase with increasing cross slopes beyond 2%, and that slopes greater than 8% significantly pose significant challenges both physiologically and physically.

Wheeling cross slope can negatively affect the cadence and power that is required for wheelchair propulsion.

The strength of specific shoulder and elbow muscles, and the ability to flex the trunk forward all affect the efficiency in performing advanced wheelchair skills particularly those associated with wheelies and caster pop-ups. Given the increased mechanical and muscular demands in these types of advanced skills, the quality of shoulder, elbow and trunk movements should be considered to balance protection of the upper extremity shoulder with being functional in the community.

3.2 Effect of Wheelchair Frame and/or Set-up on Propulsion

The configuration or set-up of a manual wheelchair affects the relationship of the person to the wheelchair, and especially to the rear wheels. The relationship to the rear wheels is important for optimal propulsion, however, may have drawbacks for other aspects of function, stability and safety. Careful balancing of these needs is required in the wheelchair prescription and fitting processes. In this section articles focused on axle position, wheels, weight of wheels, hand rims, tire pressure, and add-on devices to augment manual propulsion.

3.2.1 Axle Position of Wheelchair

Most lightweight and ultralight weight wheelchairs offer adjustable axle position. This allows the center of gravity to be adjusted appropriately for each individual, improving biomechanical efficiency and effectiveness of propulsion.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Freixes et al. 2010 Argentina Post-test N=8	Population: Mean age: 32.4 yr; Gender: males=8, females=0; Level of injury: C6=8; Level of severity: AIS A=8; Mean time since injury: 37.4 mo. Intervention: Propulsion during four wheelchair axle positions (P1 -up and forward, P2-down and forward, P3-down and backward, P4-up and backward). Outcome Measures: Speed, Acceleration, Stroke frequency, Shoulder range of motion.	 P1 demonstrated the highest propulsion speed and P3 the slowest (p<0.05). Stroke frequency was significantly higher in P1 than P2 and P3 (p=0.05). A lower range of motion was observed in P1 compared to P2 and P3 (p<0.05); the range of motion in P4 was less than P3 in the transversal plane (p<0.05). No significant shoulder range of motion differences in the coronal and sagittal planes.
Mulroy et al. 2005 USA Post-test N=13	 Population: Mean age:37.2yr; Gender: males=13, females=0; Level of injury: paraplegia=13; Time post injury: 3-37yr; Chronicity=chronic. Intervention: Propulsion of a test wheelchair with two different seat positions [posterior (SP) or anterior (SA)] during free, fast and 8% graded condition. Outcome Measures: Hand force and torque on pushrim; 3D motion of upper extremities and trunk during propulsion; Peak force (posterior and superior). 	 During free propulsion, peak superior force was low, but increased during fast and 8% graded propulsion. The superior force was lower in the SP position than in the SA position for all conditions. During free propulsion, the superior force was a negative distraction force in SP (-4.2N) and a positive distraction force in SA (3.2N). During free and fast propulsion, peak posterior force was unaltered, but increased in the SP position during 8% graded propulsion. Posterior force was

Table 4. Axle Position

Author Year Country Research Design	Methods	Outcome
Score Total Sample Size		
		 higher during fast and graded propulsion, as compared to free propulsion. 3. The SA position had a significantly lower internal rotation effect than the SP position. 4. A significantly greater transverse plane power was generated in the SA condition, as compared to the SP condition.
Samuelsson et al. 2004 Sweden Post-test N _{initial} =13; N _{Final} =12	Population: Mean age: 48.0 yr; Gender: males=10, females=2; Level of injury: paraplegia; Level of severity: Frankel A=7, D=5; Mean time in w/c/day: 11.6 hr. Intervention: Two different rear-wheel position wheelchairs [5° seat incline (P1) and 12° seat incline (P2)], while on a treadmill or a computer for 30 min/activity. Outcome Measures: Oxygen consumption, Respiratory exchange, Power output, Heart rate, Pulmonary ventilation, Freely chosen push frequency, Stoke angle, Pelvic lateral tilt, Pelvic sagittal rotation, Estimated seating comfort, Estimated activity performance.	 Changing the rear wheel position from P1 to P2 produced a change in the weight distribution (p<0.001). Changing from P1 to P2 also influenced stroke angle and push frequency during propulsion (p<0.05). Trends were not found for the remaining parameters studied.
Boninger et al. 2000 USA Post-test N=40	Population: Age range: 20.6-64.6 yr; Gender: males=28, females=12; Weight range: 43.2-106.0 kg. Height range: 154.9-20.3 cm; Level of injury: paraplegia=40; Range of time since injury: 1.3-25.2 yr; Chronicity=chronic. Intervention: Propulsion of personal wheelchair on a dynamometer at two different stable speeds (0.9 m/sec-SP1; 1.8 m/sec-SP2) and starting from a still stop to the fastest possible speed (PTU). Outcome Measures: Axle position relative to the shoulder at rest (horizontal and vertical), Pushrim mechanical variables: Frequency of propulsion, Peak and rate of rise of resultant force, Planar movement and push angle.	 Frequency of propulsion was positively correlated with axle position at SP1 (p<0.05) and SP2 (p<0.01). The push angle was decreased in all conditions when the axle position was behind the position of the shoulder (SP1, p=0.05; SP2, p<0.05; PTU, p<0.05). A larger distance between the axle and shoulder also reduced the push angle in SP1 and SP2 (p<0.05). The largest distance between the axle and the shoulder correlated with faster loading of the pushrim at SP2 (p<0.05).

Discussion

There were four studies addressing the effect of rear axle position on wheelchair propulsion with individuals with a spinal cord injury.

Boninger et al. (2000) completed a study that showed axle position relative to the shoulder was associated with significant differences in pushrim biomechanics. They found that with the axle further back relative to the shoulder there is more rapid loading of the pushrim, and increased stroke frequency was required. Additionally, individuals attained a slower speed when starting from a dead stop and there was a decrease in the push angle. An increase in the vertical

distance between the axle and the shoulder resulted in a decrease in push angle. With a decrease in push angle, force was applied to the pushrim for a shorter period and thus the frequency of propulsion had to increase to maintain speed. They suggested that providing users with a wheelchair with adjustable axle position and setting up the chair to meet the user's needs could improve propulsion biomechanics and reduce the risk of secondary injuries because of wheelchair propulsion.

Mulroy et al. (2005) studied the effect of changing the fore-aft seat position on shoulder joint forces, moments and powers during three levels of effort of wheelchair propulsion. They found that the seat posterior position resulted in a statistically significant reduction in peak superior shoulder joint forces during free, fast and graded propulsion. They concluded that the posterior seat position may reduce the risk of rotator cuff tendinopathy.

Samuelsson et al. (2004) also studied the effect of rear wheel position on wheelchair propulsion and seating aspects. A more forward position of the rear wheel had a significant effect on stroke frequency and push angle. They also reported an increase in the weight distribution with the more forward position of the wheel. However, in their study they did not find any difference between the two-wheel positions with respect to mechanical efficiency, estimated exertion, and breathlessness, seating comfort, estimated propulsion qualities, pelvic position or activity performance.

Freixes et al. (2010) also assessed the changes in speed, acceleration, stroke frequency and shoulder ROM in relation to four different axle positions. The study showed that the up and forward axle position resulted in an increase in speed and acceleration with a higher stroke frequency and a decreased shoulder ROM. The axle position of down and backward axle position resulted in a lower speed and acceleration with a lower stroke frequency and an increased shoulder ROM. The authors indicated that these were clinically important findings for wheelchair propulsion in their homes.

Conclusion

There is level 4 evidence (from four post-test studies, Mulroy et al. 2005; Samuelsson et al. 2004; Boninger et al. 2000; Freixes et al. 2010) that the more forward position of the rear wheel improves pushrim biomechanics, shoulder joint forces, push frequency and stroke angle.

Manual wheelchairs with adjustable axle position appear to improve wheelchair propulsion and reduce the risk of upper extremity injury.

3.2.2 Weight of Wheelchair

Wheelchair propulsion may be affected by the weight of the wheelchair as well as the weight of the person using the wheelchair. Manual wheelchairs are available in three general weight categories: standard, lightweight and ultralight.

Table 5. Weight Addition of Wheelchair

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Bednarczky & Sanderson 1995 Canada Prospective Controlled Trial N=20	Population: Mean age: 33.5 yr; Gender: males=7, females=3; Mean weight: 68.5 kg; Weight range: 53.7-84.7 kg; Level of injury: paraplegia=10, NR=10. Intervention: Propelling across a runway using the Kuschall Champion 3000 wheelchair at 2 m/sec. Three conditions: 1) no weight added; 2) 5 kg added; 3) 10 kg added. Five propulsion trials were completed for each condition. Outcome Measures: Propulsive and recovery phases timing, Angular displacements of extremities (elbow flexion-extension, shoulder flexion- extension, shoulder abduction, trunk flexion-extension).	 In all conditions, grab and release (wheel contact to release) did not have a significant variation. No significant effects were found regarding the angular variables in weight conditions; however, significant group effects were found for elbow flexion-extension (p=0.003), shoulder flexion-extension (p=0.0007), and shoulder abduction (p=0.0003).
Beekman et al. 1999 USA Pre-Post N=74	 Population: Mean age: 26.2 yr; Gender: males=69, females=5; Level of injury: paraplegia=44, tetraplegia=30, C6=14, C7-8=16, T2-8=19, T10-L1=25. Intervention: Using a standard wheelchair (SWC) and an ultralight wheelchair (UWC) to propel self for 20min on an outdoor track (60.5 m in circumference). Outcome Measures: Speed and distance travelled; Oxygen consumption – Douglas Bag technique; Heart rate; Vital capacity; all at 3-5 min, 9-10 min, 14-15 min, 19-20 min. 	 Subjects travelled a longer distance and at a faster speed in the UWC versus the SWC for T2-8 (p<0.00), T10-L1 (p<0.01) and subjects with tetraplegia as a whole (p=0.01), but not separately. Oxygen consumption also decreased for T2-8 (p<0.00) and T10-L1 (p<0.01). Distance and speed differed between subjects with tetraplegia and paraplegia independent of wheelchair or time (p<0.00). C6 had a significantly high oxygen consumption level, compared to all other subgroups (p<0.01). With the exception of C6, all subgroups increased speed over the 20min interval, regardless of wheelchair used.
Parziale 1991 USA Pre-Post N=26	 Population: Age range: 20-40 yr; Gender: males=26, females=0; Level of Injury: paraplegia (T1-T6)=8, paraplegia (T7-L4)=12, tetraplegia (C5-C8)=6; Mean time since injury: 6 mo. Intervention: Patients performed a sprint test in both a study standard and a lightweight wheelchair at maximum speed for 400 ft followed by an endurance test of both wheelchairs in which patients had to propel as far as they could in 4 min. Outcome Measures: Systolic and diastolic blood pressure, Pulse rate, Respirations per minute, Time performance, Distance. 	 Systolic blood pressure was significantly different between levels of injury (high paraplegia, low paraplegia and tetraplegia) for both the wheelchair sprint and endurance tests (both p<0.001) but not between wheelchair type. Time performance on the sprint test was significantly different between levels of injury (p<0.001) and wheelchair type (p<0.001) on the sprint test with the lightweight wheelchair achieving faster speeds than the conventional wheelchair. Distance covered in the endurance test was significantly different between levels of injury (p<0.001) but not between wheelchair type. No significant differences were reported between level of injury and wheelchair type with diastolic blood

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
		pressure, pulse rate and respirations per min.
Collinger et al. 2008 USA Post-test N=61	Population: Mean age: 43.1 yr; Gender: males=49, females=12; Mean height: 1.76 m; Mean weight: 75.9 kg; Level of injury: paraplegia=61; Mean time since injury: 14.6 yr; Chronicity=chronic. Intervention: Propulsion of personal wheelchair on a dynamometer at three different speeds (self-selected-SP1, 0.9m/sec-SP2; 1.8 m/sec-SP3). Outcome Measures: Demographic differences, Subject characteristics, Shoulder biomechanics.	 As propulsion speed increased, so did shoulder joint loading. There was an increase in mean resultant force from 54.4 N at SP2, to 75.7 N at SP3 (p<0.001). Of the demographic variables, body weight had the largest influence on shoulder forces. When the arm is extended and internally rotated, peak shoulder joint loading is indicated, increasing the possibility of shoulder injury.
Boninger et al. 1999 USA Post-test N=34	Population: Age range: 20.7-53.1 yr; Gender: males=23, females=11; Level of injury: paraplegia=34; Range of time since injury: 1.2-25.2 yr; Chronicity=chronic. Intervention: Self propulsion of personal wheelchair on a dynamometer at 0.9 m/sec (SP1) and 1.8 m/sec (SP2). Outcome Measures: Median and ulnar nerve conduction, propulsion velocity, Frequency of propulsion stroke, Peak force, Maximum rate of rise.	 Rate of rise (resultant force) and peak pushrim force and subject weight were significantly correlated at SP1 and SP2 (r=0.59, p<0.001). With regards to the nerve conduction studies, subject weight was significantly correlated with mean median nerve latency (r=0.36, p<0.01) and mean median sensor amplitude (r=-0.43, p<0.01). Subject height was significantly correlated to mean sensory amplitude (r=-0.58, p<0.01). Peak force was related to mean median nerve latency (r=0.59, p<0.001), and was inversely related to mean sensory amplitude (r=-0.59, p<0.01).

Discussion

Effect of body weight on propulsion

Bednarczky and Sanderson (1995) studied the effect of adding weight to a wheelchair on the angular variables of wheelchair propulsion. Twenty individuals with paraplegia were tested propelling a wheelchair with no additional weight and then five kg and 10 kg added. With the addition of the weight the proportion of the wheeling cycle spent in propulsion did not change. Also, there was no change in the angular kinematics (shoulder flexion/extension, elbow flexion/extension, shoulder abduction and trunk flexion/extension). The authors concluded that a change in the range of five kg to 10kg in system weight of either the user or the wheelchair will probably not affect the wheeling motion in short distance, level wheeling.

Boninger et al. (1999) found a link between pushrim biomechanics and median nerve function. They also found a link between body weight and median nerve function. Increased body weight was felt to increase the rolling resistance of the wheelchair and increase forces required to propel the chair. They also found that regardless of body weight, those who rapidly load the pushrim during the propulsive stroke may be at greater risk for carpal tunnel syndrome. They suggest that weight loss and training to incorporate smooth low impact strokes may reduce the chance of median nerve injury. Set up and maintenance of the wheelchair was also regarded as important.

Collinger et al. (2008) investigated shoulder biomechanics during wheelchair propulsion in 61 persons with paraplegia. Their results indicate that shoulder pain does not affect the way a subject propels a wheelchair. This suggested pain or shoulder pathology did not affect propulsion patterns. They also found that at faster speeds shoulder joint forces and moments increased. When comparing the demographic variables between the subjects, body weight was the only indicator of shoulder joint forces. Heavier subjects experienced an increased loading and greater resultant forces. They suggested that manual wheelchair users maintain a healthy body weight and if that was not possible then the user be prescribed a lightweight wheelchair with an adjustable axle.

Effect of wheelchair weight on propulsion

Beekman et al. (1999) tested the propulsion efficiency of individuals with paraplegia and tetraplegia using an ultralight wheelchair (UWC) and a standard wheelchair (SWC). Their results indicated that the use of a UWC by individuals with paraplegia increased speed and distance traveled as well as decreased oxygen cost. The use of a UWC for individuals with tetraplegia was also beneficial although the differences were not as great. However, the effect of weight was not clear. The different wheelchair features that would account for the increased efficiency with a UWC were not studied.

Parziale 1991 also compared propulsion differences for people with low level paraplegia (T7-12), high level paraplegia (T1-6) and quadriplegia (C5-8) using a study standard and lightweight wheelchair in a 400 m sprint and a duration test of four minutes continuous propulsion. Findings indicate that the outcome measures of blood pressure, respiration and pulse rate were statistically different for the quadriplegia group only suggesting that the lightweight wheelchair was more efficient to propel. The author further examined the sprint data, finding that the differences existed only during the initial push phase of the sprint, further suggesting that the benefit of the lightweight wheelchair was in the first few pushes to start propulsion, but not to sustain propulsion. The author does note that this information should not be the basis for deciding on the wheelchair frame type, but that the decision should be based on a full assessment of all the individual's needs.

Conclusion

There is level 2 evidence (from one prospective controlled study; Bednarczky & Sanderson, 1995) that adding 5-10 kg to the weight of a particular wheelchair will not affect the wheeling style under level wheeling, low speed conditions.

There is level 4 evidence (from two pre-post studies; Beekman et al. 1999 and Parzaile 1991) that the use of lighter weight wheelchairs results in improved propulsion efficiency for those with SCI particularly at the start of propulsion.

There is level 4 evidence (from two post-test studies; Boninger et al. 1999; Collinger et al. 2008) that user weight is directly related to pushrim forces, the risk of median nerve injury and the prevalence of shoulder pain and injury.

The use of lighter weight wheelchairs may improve propulsion efficiency in those with SCI particularly at the start of propulsion.

Body weight management is important in reducing the forces required to propel a wheelchair and reducing the risk of upper extremity injury.

3.2.3 Wheelchair Frame and Vibration

The choice of wheelchair frame and wheelchair wheels play an important part in the management of spasticity and perceived comfort by decreasing the amount of whole-body vibration felt by the individual with a SCI when traversing over rough surfaces such as bumps in sidewalks or rumpled carpets (Vorrink et al. 2008).

Table 6 Wheelchair Wheels

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Vorrink et al. 2008 Canada RCT PEDro=4	 Population: Mean age: 46.2 yr; Gender: males=10, females=3; Level of injury: C=3, T=10; Severity of injury: complete=7, incomplete=2, unknown=4. Intervention: Subjects were asked to perform an obstacle course in their own wheelchairs and were randomly assigned one of two types of wheels: spinergy or steel traditional spoke wheels. Outcome Measures: Average speed, Peak acceleration, Root-mean-square, Visual Analog Scale (VAS). 	 The two wheel types did not differ in their average speed, peak acceleration, and RMS or peak power. Overall, the footplate compared to the axel had higher peak accelerations (p<0.001) and RMS values (p<0.001). Spasticity and comfort measures on the VAS and the overall VAS did not differ significantly between the two wheel types. Steel spoked wheels showed a trend towards being rated as higher in spasticity on 8/9 obstacles (p=0.06).
N=13	Effect Sizes: Forest plot of standardized mean of calculated from pre- and post-intervention data. Vorrink 2008; Spinergy Wheelchair	differences (SMD ± 95%C.I.) as neels (Vibration & Spasticity) (-0.74,0.80)
Garcia-Mendez et al. 2013 USA Post Test N=37 (SCI=25)	Population: Mean age: 47.6 yr; Gender: males=32, females=5; Injury etiology: SCI=25, amputation=6, MS=3, other=3; Level of injury: paraplegia=20, tetraplegia=5; Mean duration of w/c use: 15.0 yr. Intervention: Exposure to whole body vibration was measured over a 2 wk period using a vibration data logger (VDL) at the back support and the seat and a manual wheelchair data logger (MDL) which measures distance speed and continuous movement. Outcome Measures: Shock-sensitive vibration evaluation method (VDV) of the seat surface and back support, duration of vibration exposure, frequency-weighted acceleration.	 Participants spent an average of 13.07 hr/day in their wheelchairs. Nearly 31% of participants were exposed to vibration levels at the seat within the health caution zone, and the rest of the participants were exposed to levels above this zone. Exposure to vibration measured at the back support was lower and tended to be localized within the health caution zone in comparison to the seat. Suspension systems did not significantly decrease the vibration exposure at the wheelchair frame.

Discussion

Whole body vibration levels measured at the seat surface and the back support were found to be higher than the health caution zone levels recommended by ISO 2631-1 (Garcia-Mendez et al. 2013). Vibration measured in the rigid frames and frames with suspension were noted to be lower than that measured on a folding frame wheelchair, but no comparison calculations were provided. The authors indicate that the use of suspension systems added to the frames did not significantly reduce vibration, but data or comparison calculations were not provided.

Conclusion

There is level 2 evidence (from one randomized controlled trial; Vorrink et al. 2008) that the use of Spinergy wheels verses standard steel-spoked wheels was no more effective in reducing spasticity by absorbing vibration forces when wheeling.

There is level 4 evidence (from one post-test study; Garcia-Mendez e t al. 2013) to suggest that whole body vibration exposure for people who use manual wheelchairs are within or above the health caution zone established by ISO.

There is insufficient evidence to determine if Spinergy wheels are more effective in reducing spasticity by absorbing vibration forces when wheeling than standard steel-spoked wheels.

3.2.4 Wheelchair Tire Pressure

Different types of tires are available to manual wheelchair users including pneumatic and solid tires. There are advantages to pneumatic tires over solid tires but they do require regular maintenance of air pressure. Under inflated tires affects wheelchair propulsion.

Table 7	Wheelchair	Tire Pressure

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Sawatzky et al. 2005 Canada Post Test N _{Initial} =17; N _{Final} =14	 Population: Mean age: 35.3 yr; Gender: males=11, females=3; Level of injury: paraplegia=17. Intervention: Propulsion of personal wheelchair over a linoleum floor at a preferred speed for 8 min with 4 different tire pressures (100, 75, 50, 25 psi). Outcome Measures: Energy expenditure, Heart rate-Polar heart monitor, Oxygen consumption-Cosmed K4 oxygen system, Distance traveled. 	 When tires were deflated to 50 and 25 psi, there was an increase in energy expenditure (p<0.01 and p<0.001, respectively). The decrease in pressure indicated a 12.2% (50psi) and 24.1% (25psi) increase in energy used. A correlation was found between heart rate and oxygen consumption (r=0.74). Higher lesions had a lower correlation (above T6, r=0.55), than lower lesions (below T6, r=0.82).

Discussion

Sawatzky et al. (2005) investigated the effect of tire pressure on wheelchair propulsion. Tires deflated to 50 and 25 psi from the recommended 100 psi resulted in an increase of energy expenditure of 12.2 % and 24.1%, respectively. Tire pressure does effect energy cost of wheelchair propulsion but not until they are deflated to more than 50% of the recommended inflation.

Conclusion

There is level 4 evidence (from one post-test study; Sawatsky et al. 2005) that tire pressure effects energy expenditure only after the tire has been deflated by 50%.

Tires with less than 50% inflation causes an increase in energy expenditure.

3.2.5 Wheelchair Handrims

Traditionally, handrims on lightweight and ultralight weight wheelchairs consist of a metal hoop rigidly mounted to the wheel. During propulsion, this hand rim is contacted with each push stroke. Research suggests that the use of rigid hand rims may be a contributing factor to developing repetitive strain injuries of the hand, elbow and shoulder. The two studies included in this subsection examined the use of flexible hand rims.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Richter et al. 2006 USA Post Test N _{Initial} =24; N _{Final} =23	Population: Mean age: 35.0 yr; Gender: males =18, females=6; Mean weight: 71.4 kg; Level of injury: paraplegia=22, spina bifida=2; Mean duration of w/c use: 16 yr; Chronicity=chronic. Intervention: Propulsion of personal wheelchair on a treadmill with varying inclines (level, 3°, 6°) and using a standardized uncoated handrim (SUH) and a high friction flexible handrim (HFH). Outcome Measures: Electromyographic data-maximum voluntary contraction, Total muscle exertion, Peak and total muscle exertion per push.	 HFH decreased peak muscle activation and total muscle exertion. An 11.8% reduction in peak muscle activation (p=0.026), and a 14.5% (p=0.016) reduction in total muscle exertion, were apparent with use of the HFH versus the SUH.
Richter & Axelson 2005 USA Post Test N=17	Population: Mean age: 37 yr; Gender: males=10, females=7; Injury etiology: SCI=16, spina bifida=1. Intervention: Part 1: Participants used their own manual wheelchair with their rear wheels replaced with the Variable Compliance Hand-Rim Prototype (VCHP) test wheels. Participants completed a mobility activity test course (uphill, downhill, slalom, level sprint, pushing and carpet) in three different hand rim compliance settings (ridged, C1, C2, C3); testing stopped once the participant found the hand rim compliance to be too soft. Part 2: Participants propelled their own manual wheelchairs with the rear wheels replaced with a propulsiometer on a treadmill for up to 5 min using each hand- rim condition (rigid, C1, C2, C3) for four grade/speed combinations with a 15 min rest period between each test combination. Outcome Measures: Peak hand-rim force, Metabolic demand and rate of loading at impact, Participant feedback related to	 Participants felt that the use of the compliant hand rims did not compromise their ability to maneuver/control the wheelchair. No participants found C1 too soft; C2 and C3 were too soft for 29% and 47% of participants, respectively; 24% felt the hand rim could be softer than C3. C1 was the only hand-rim condition that had a statistically significant difference from rigid hand-rim for push angle (an additional 3.5° angle on 2% grade compared to the rigid rim). Push angle, push frequency and recovery time tended to decrease with an increase in grade; push time increased with increasing grade No statistically significant differences were found between the rigid hand rim and any of the other conditions (C1, C2 or C3) for peak resultant and in- plane resultant force relationships. For all hand-rim conditions, the trend was an increasing peak hand-rim force as the grade increased.

Table 8 Wheelchair Handrims

Author Year Country Research Design Score Total Sample Size	Methods		Outcome
	acceptability of different hand rim compliance levels.	7. 8.	No statistically significant differences were found between the compliant and rigid hand rims in terms of: 1) resulting peak wheel moment and estimated contribution of tangential force. No significant differences were found for metabolic demand between the rigid and C3 hand-rims.

Summarized Level 5 Evidence Studies:

The following level 5 evidence studies have been reviewed, and the overarching findings from the studies are highlighted in this section. As noted at the start of this chapter, these types of studies are not included in the discussion or in the conclusions.

Dieruf et al. (2008) surveyed 87 people who purchased a specific ergonomic contoured hand rim to gain their perspective on the impact the hand rims had on their propulsion. Participants reported improved comfort in propulsion, reduced upper extremity symptoms and for people over the age of 50, improved ability to maintain functional abilities for those experiencing wrist or hand pain. The survey results indicated that there was greater satisfaction with the contoured hand rims the longer they were used; only nine participants reported negative changes following use of the contoured hand rims, and only seven participants had stopped using the rims.

Discussion

Richter et al. (2006) investigated finger and wrist flexor activity when using a flexible handrim as compared to a standard handrim. A flexible hand rim consisting of high friction urethane spanning between a standard tubular handrim and the wheel has been developed. The urethane takes the shape of the hand when gripping. 24 subjects pushed their own wheelchairs on a level surface and at three- and six-degree grades using both types of handrims. Use of the flexible handrim significantly reduced wrist and finger flexor activity when averaged across all grade conditions. This suggests that over a period of years flexible handrims may be a factor in preserving upper extremity health.

Richter et al. (2005) explored the balance between compliance hand rims and the acceptability of this type of rim to 17 participants who propel manual wheelchairs. They note previous research indicating that compliant rims reduce the impact loading during the push phase but are found to be an unfavourable option by people who propel manual wheelchairs. This study found that participants were accepting of a moderately compliant hand rim. It also found that compliant hand rims did not differ greatly from rigid hand rims in relation to push frequency, push angle, push timing, and peak forces. Where differences were noted was in the forces that contribute to impact loading, and subsequently increase the risk of repetitive strain injuries. Impact forces, with an equal or decreased peak rate of rise at impact loading of hand on the rim and a decrease in the average rate of rise of the contact force. The authors suggest that moderately complaint rims are acceptable to most people who propel manual wheelchairs and have been shown to reduce the impact forces associated with propulsion in comparison to standard rigid hand rims.

Conclusion

There is level 4 evidence (from one pre-post study; Richter et al. 2005 and one post-test study; Richter et al. 2006) that a flexible or compliant hand rim can reduce impact forces and reduce wrist and finger flexor activity during wheelchair propulsion.

There is level 4 evidence (from one pre-post study; Richter et al. 2005) that flexible hand rims are found to be acceptable to people who propel manual wheelchairs, with perceived benefits of comfort, reduced upper extremity pain and improved propulsion.

Use of flexible handrims may reduce upper extremity strain thereby reducing discomfort and pain symptoms during wheelchair propulsion.

3.2.6 Pushrim-Activated Power-Assist Wheelchairs

For many years, there were three main types of wheelchairs available to those individuals with disabilities: manual wheelchairs, scooters and electric powered wheelchairs. Pushrim-activated power-assist wheelchairs (PAPAW) have become an option for wheelchair users. The PAPAW is a combination of a manual wheelchair and electric powered wheelchair where a motor is linked to the pushrim by way of the rear hub to reduce the effort required to propel.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Kloosterman et al. 2013 Netherlands Systematic Review of published studies between 1980-2012 N=15	 Method: Studies were included if they investigated the effect of power-assisted wheel-chair propulsion on human functioning compared to hand-rim or powered wheelchair propulsion; was a clinical trial or (randomized) controlled trial; was published as a full-length paper in a peer-reviewed journal in the English language. Databases: The Cochrane Library, REHABDATA, CIRRIE and CINAHL. Level of evidence: 15 crossover trials were assessed for their methodological quality using the 'Checklist for Measuring Quality' of Downs and Black Maximum attainable score=32 Questions/measures/hypothesis: 1. To examine the current knowledge about transition from a hand-rim or powered wheelchair. 	 The Downs and Black score assigned to all studies ranged between 9-15 points out of the maximum score of 32. All compared power-assisted to hand- rim or powered wheelchair use. Results from quantitative analysis: Movement analysis of the arm during power-assisted propulsion compared to hand-rim propulsion was found to be significantly associated with a decrease in wrist ulnar-radial deviation and flexion-extension and decreased, flexion-extension and internal-external rotation in the shoulder. There was no significant association between either type of propulsion and shoulder abduction. Healthy populations found the hand- rim wheelchair more effective for tasks requiring greater control, whereas power-assisted wheelchairs were more preferred for activities within a confined space (or indoors) whereas powered wheelchairs were preferable for outdoor activities. There were no significant differences found for the association between wheelchair type (power-assisted, hand-rim or powered) and activity

Table 9 Pushrim-Activated Power-Assist Wheelchairs (PAPAW) for SCI

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
		 social participation, and psychological outcomes, within a home environment. Results from the qualitative analysis: 6. Most participants experienced increase ease of propulsion with a power-assisted wheelchair; 7. Most rated power-assisted prolusion on level and inclines and carpet as (very) easy compared to hand-rim wheelchair propulsion. 8. Some limitations were that power-assisted wheelchair in confined spaces were difficult to manoeuvre, car transfer from power-assisted WC wheels can be difficult. 9. Other positive experiences were accessibility to new and different activities, and more independence.
Giesbrecht et al. 2009 Canada RCT PEDro=6 N=8	Population: Age Range: 33-63 yr; Gender: males=6, females=2. Intervention: Participants were randomly assigned use of a pushrim-activated power-assisted wheelchairs (PAPAW) or their own power wheelchair (PWC) for 3 wk and then crossed over to the alternative for 3 wk. Outcome Measures: Activity Level: Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST, Functioning Every day with a Wheelchair (FEW), Psychosocial Impact of Assistive Devices Scale (PIADS); Participation Level: Canadian Occupational Performance Measure (COPM).	 Temporal Outcomes: Mean hr per day spent in PAPAW (5.5 hr, SD=3.63) and PWC (6.1 hr, SD=5.36) and not significantly different (t(7)=-0.33, p=0.75); Mean time spent per day in any wheelchair (manual and power wheelchair) was 8.83 hr (SD=5.34) and 9.17hr (SD=5.83) for the PAPAW and PWC blocks; not significantly different (t(7)=-0.54, p=0.60); Total number of hr per week participating in identified occupations (56.1, SD=52.0; 62.8, SD=42.6) and not significantly different between PAPAW and PWC blocks (t(7)=-0.33, p=0.75); Outcome Measures at Activity Level (Quest, FEW, PIADS): No identified difference identified between PAPAW and PWC on Quest Device subscale median (range) PAPAW score 3.8 (3.0-4.5) versus3.8 (1.9-5.0); p=0.945; PIADS Self-Esteem subscale demonstrated a statistically significant difference with PWC rated higher median (range) PAPAW score 7.5 (-2-18); p=0.016. Outcome Measure at Participation Level (COPM): Performance Component: no statistically significant difference found median PAPAW score 6.5 (4.0-9.0) versus median PWC score 8.2 (4.3-10.0); p=0.195

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
		 Satisfaction Component: no statistically significant difference found median PAPAW score 7.2 (2.7-8.4) versus median PWC score 8.2 (2.3 - 10.0); p=0.469.
	Effect Sizes: Forest plot of standardized me calculated from pre- and post-intervention da Giesbrecht 2009; Pushrim-Activate	ean differences (SMD ± 95%C.I.) as ata. ed, Power-Assisted Wheelchair (PPW) $0.06 \left(\frac{-1.44, 1.55}{1}\right)$ $0.06 \left(\frac{-1.43, 1.56}{1}\right)$
	FEW-2	0.00 (-1.50,1.50)
	PIADS PIADS-Competence	0.86 (-0.71,2.42)
	PIADS-Adaptibility PIADS-Self Esteem	2.73 (0.66,4.80)
	COPM	0.60 (-0.93,2.13)
	-2 -1.5 -1 -0.5 Favours Control Standardiz	0 0.5 1 1.5 2 red Mean Difference (95%C.I.) Favours Treatment
Nash et al. 2008 USA RCT PEDro=5 N=18	Population: Mean age: 39.1 yr; Gender: males=18, females=0; Level of injury: paraplegia=12, tetraplegia=6; Severity of injury: complete=18. Intervention: Study participants were asked to complete five testing sessions during which they were asked to propel their chairs randomly on either their own wheels or the pushrim-activated power- assisted wheelchairs (PAPAW) wheels. Subjects performed each test twice. Outcome Measures: Oxygen consumption, Distance, Energy cost, Ratings of perceived exertion (RPE).	 6 min steady state test sessions; Oxygen Uptake; VO₂ significant effects found for group (F1.32=17.2, p<0.001), time F3.96=37.6, p<0.001) and group x time interaction (F3.96=11.2, p<0.001); significant increases at each time point between 0 and 6 for paraplegia, not for tetraplegia. Distance propelled: significant effect for group (F1.32=50.3, p<0.001), type of wheel (F1.32=27.3, p<0.001), time (F3.96=247.5, p<0.001) and group interaction effect (F3.96=14.7, p<0.001) with individuals with paraplegia traveling farther than tetraplegia and PAPAW traveling farther than traditional push wheels. Energy Costs: significant effort for wheel was found for energy cost (F1.32=9.7, p<0.01) with the traditional wheels requiring greater energy costs than PAPAW. Perceived Exertion: time was the only significant effect observed (F3.96=52.3, p<0.001) with score getting significantly higher at each stage for all subjects. Twelve Minute Test Sessions: Oxygen Uptake: Vo2 significant

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
		 effects were found for group (F1.32=14.8, p=0.001), time (F6.192=18.0,p<0.001) and the group x time interaction (F6.192=7.5, p<0.001), significant increases at each time point between 0 and 12 for paraplegia, not tetraplegia. 6. Distance Propelled: significant effects found for group (F1.32=59.6,p<0.001), type of wheel (F1.32=66.9, p<0.001), time (F6.192=216.5, p<0.001) the group x time interaction (F6.192=22.3, p<0.001) and wheel x time interaction (F6.192=25.8, p<0.001) with persons with paraplegia travelling farther than tetraplegia and PAPAW travelling farther than regular wheels, magnitude of change greater in persons with paraplegia and when using PAPAW. 7. Energy Costs: significant effect for type of wheel (f1.32=20.4, p<0.001) with traditional wheels requiring higher energy cost than PAPAW. 8. Perceived Exertion: RPE, time (F6.192=89.6; p<0.001) and wheel x time interaction (F6.192=2.2; p<0.05) were different with scores rated significantly higher at each stage across all subjects and in overall score for PAPAW being lower than traditional wheels; significant increase in RPE between time 0 and 12 for both wheels and PAPAWs with change greater in customary wheels at time 2, 4, and 12.
	Effect Sizes: Forest plot of standardized me calculated from pre- and post-intervention da	an differences (SMD ± 95%C.I.) as
	Nash et al. 2008; Pushrim-Activated, Powe	er-Assisted Wheelchair (PAPAW) Paraplegia
	V02	
	Energy Costs	0.38 (-0.43.1.19)
	Distance	
	-2 -1.5 -1 -0.5 Favours Control Standardized N	U U.S 1 1.5 2 Mean Difference (95%C.I.) Favours Treatment

Author Year Country Research Design Score Total Sample Size	Methods		Outcome	
	Nash et al. 2008; Pushrim-Activ VO2 Energy Costs Distance	-0.5	-Assisted Wheelchair (PAPAW) Tetraplegia 0.23 (-0.91,1.36) 0.29 (-0.85,1.43) 0.07 (¹ / ₁ 1.06,1.20) 0 0.5 1 1.5 2	
	Favours Control Sta Population: Mean age: 38.8 yr; Generation: and a second statements and a second s	ndardized M der:	 All PAPAW showed a significantly greater decrease in oxygen consumption and heart rate during 	
Guillon et al. 2015 France RCT PEDro=5 N=52	Intervention: Individuals were evaluation on the use of manual wheelchairs and three pushrim-activated power-assist wheelchairs (PAPAW): Servomatic A Servomatic B and E-motion. The studies conducted in three phases: phase 1 consisted of participants propelling all wheelchairs on a dynamometer (n=10 phase 2 consisted of using wheelchair indoor and outdoor courses (n=46), we phase 3 evaluated participants' ability transfer themselves and their wheelch into and out of cars (n=10). Participart used all wheelchairs for each phase, order of wheelchair use was randomized for each participant. Outcome Measures: Oxygen consumper unit time (VO ₂), Heart rate, Comp time, Handrim push frequency, Patier satisfaction.	ated d ed ly was l the)), rs on thile to nairs ats the zed nption letion at	 consumption and heart rate during phase 1 compared to manual wheelchairs (p<0.005). There were however no significant differences between the three PAPAW groups. 2. During the outdoor tests, a MANOVA revealed statistically significant effects of wheelchair type (p<0.0001), lesion level (p<0.0001), and interaction between wheelchair type and lesion level (p<0.0004) on several dependent variables (completion time, handrim push frequency, maximal heart rate and patient satisfaction). 3. For the indoor tests, a MANOVA revealed statistically significant effects of wheelchair type (p<0.0001) on completion time, handrim frequency and patient satisfaction. 4. More participants required help for transfers with PAPAW compared to manual wheelchairs (p=0.04) 	
Ding et al. 2008 USA Pre-Post N=15	Population: Mean age: 38.3 yr. Gene NR; Level of severity: tetraplegia=15; time since injury: 15.8 yr. Intervention: Individuals used their of personal wheelchairs for 2wk and the pushrim-activated power-assisted wheelchairs (PAPAW) for 2wk. Mobili levels with both wheelchairs were rec by a datalogger. Outcome Measures: (Primary): Daily distance traveled, Average speed, Accumulated driving (movement) time Number of starts/stops, Maximum pe continuous movement, Maximum dist of continuous movement. (Secondary variables): Percentage of time between 0.5m/s, Percentage of time between 0.5m/s and 1.0m/s, Percentage of tim over 1.0m/s, Psychosocial Impact of Assistive Devices Scale (PIADS).	der: Mean n ty orded / e, riod of ance en	 No significant differences were found for the distance traveled with both wheelchairs (p=0.009). There was a statistically significant difference found between PAPAW and personal manual wheelchairs for the speed traveled (PAPAW: average speed=0.74±0.31 m/s; Personal: average speed=0.60±0.23 m/s, p=0.03). Participants traveled similar distances in the PAPAW trial and the own chair trial (p=0.16). Results of secondary mobility variables were the following: Number of starts/stops (per 1000 m): [PAPAW: 65.4±25.7 m; Personal wheelchair: 78.3±21.8 m; Own Chair Trial (2 wk) Personal wheelchair: 75.2±22.7 m]. Maximum period of continuous movement (min): [PAPAW: 3.0±2.4 min; Personal Wheelchair: 2.1±2.7 min; Own Chair Trial (2wk) Personal 	

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
		 Wheelchair: 3.3±4.6 min], Maximum distance of continuous movement (m): [PAPAW: 229.2±289.4 m; 135.4±248.7 m; Own Chair Trial (2wk) Personal Wheelchair: 229.8±409.3 m). 5. Self-perceived PIADS assessment revealed no significant differences for ratings of adaptability, competency, and self-esteem between the PAPAW and the traditional manual wheelchair (p=0.18, p=0.07 and p=0.09, respectively).
Finley et al. 2007 USA Pre-Post N=17	Population: Mean age: 46 yr; Gender: males=9, females=8; Injury etiology: SCI=11, spina bifida=1, polio=1, stroke=1, ataxia=1, spinal stenosis=1, rheumatoid arthritis=1. Intervention: Individuals used a manual 2- speed geared wheelchair wheel over five months (MAGICWheels intervention). Outcome Measures: The Wheelchair Users Shoulder Pain Index (WUSPI); Wheelchair Users Functional Assessment (WUFA); Timed hill climb test with rating of perceived exertion (RPE).	 There was a statistically significant reduction in WUSPI (shoulder pain score) with the MAGICWheels intervention at wk 2 (p=0.0444); these results remained statistically significantly different from baseline until wk 16 (p=0.015), however not at wk 20 (p=0.062). Post-hoc correlation analysis revealed no significant relationship between duration of wheelchair use and pain reduction for any wks of the MAGICWheels intervention (p>0.05). After the 5-mo period, there was no significant difference in WUFA scores (p>0.05).
Haubert et al. 2005 USA Pre-Post N=5	Population: Mean age: 48 yr; Gender: males=5, females=0; Injury etiology: tetraplegia=4, paraplegia=1; Mean time since injury: NR. Intervention: To compare the propulsion characteristics between a standard manual WC and each of three pushrim-activated power-assisted wheelchairs (PAPAW): iGLIDE Xtender with a 1.5X power-assist; an e-motion with settings adjusted to mid- sensitivity; and maximum power-assist. Outcome Measures: Energy Expenditure (average heart rate and O ₂ consumption); Average velocity (m/min±1SD); Average cadence (cycles/min±SD).	 Compared to standard WC propulsion, during iGLIDE propulsion, velocity increased for two subjects due to increased cycle length and cadence (mean increases: 15% and 28%), respectively. Average velocity decreased in the iGLIDE for three subjects as a result of decreased cadence and cycle length (mean decreases=19%, 46%, 33%, respectively). Compared to standard WC propulsion, during Xtender propulsion, velocity increased for 3/5 participants by 20%, 16% and 40%. Velocity increased from increased cadence for one subject by12% and decreased by 7% for another subject, from decreased cadence. Compared to standard WC propulsion, during propulsion, velocity increased for 3/5 participants by 20%, 16% and 40%. Velocity increased from increased cadence for one subject by12% and decreased by 7% for another subject, from decreased cadence. Compared to standard WC propulsion, during propulsion, velocity increased by 22% from increased cycle length and cadence for one subject. For another, it slightly increased by 3% from increased cycle length; and further decreased for three subjects by 5%, 7% (from decreased cadence) and 5% (from reduced cycle length), respectively.

Author Year Country Research Design Score	Methods		Outcome
Total Sample Size		 4. 5. 6. 7. 	Compared to standard WC propulsion, three subjects were found to have a decreased average O ₂ heart rate and consumption An increase in O ₂ consumption during PAPAW propulsion was observed during iGLIDE propulsion by 5% for one subject; another subject by 18% for Xtender; and by 25% for propulsion. On average, the O ₂ consumption cost decreased for all subjects during Xtender and propulsion in each PAPAW. On average, there was an increase in O ₂ cost for two subjects with respect to
			propulsion of iGLIDE, and similar O ₂ costs as standard WC for another.
Algood et al. 2004 USA Pre-Post N=15	Population: Age range: 27-52 yr; Gender: males=12, females=3; Weight range: 45- 116 kg; Height range: 152-193 cm; Level of injury: tetraplegia=15; Chronicity: chronic. Intervention: Propulsion of personal wheelchair and pushrim-activated power- assisted wheelchairs (PAPAW) in dynamometer at 0.9 m/s for 3 min/trial, with three difference resistances (10 W, 12 W, 14 W). Outcome Measures: Mean steady state oxygen consumption, Ventilation, Heart rate, Mean stroke frequency, Maximum upper extremity range of motion (ROM).	1. 2. 3. 4.	Subjects had a significant reduction in ventilation and oxygen consumption in all PAPAW trials compared to manual wheelchair trials (p<0.05). When using the PAPAW, heart rate only decreased in the 14 W condition (p<0.001) and stroke frequency only decreased in the 10W and 12W conditions (p=0.001). When using the PAPAW, horizontal flexion/extension, shoulder flexion/extension, shoulder flexion/extension, internal/external rotation and wrist ulnar and radial deviation ROMs were all significantly decreased in all weight resistance conditions (p<0.05). Forearm supination/pronation ROM was significantly decreased in the 12 W and 14 W trials (p<0.01) when using the PAPAW. Elbow and wrist extension/flexion ROM were also significantly reduced in the 14 W trials (p<0.05).
Fitzgerald et al. 2003 USA Pre-Post N=7	Population: Mean age: 42.1 yr; Gender: males=5, females=2; Level of injury: paraplegia=7; Time since injury range: 5- 22 yr; Chronicity=chronic. Intervention: Manual wheelchair and pushrim-activated power-assisted wheelchairs (PAPAW) wheelchair. Outcome Measures: Distance traveled and velocity-Data logger; Qualitative information-Visual Analog Scale.	2.	No significant differences were found between the subject's personal wheelchair and the PAPAW for distance or velocity; however, some trends were noted. Subjects would use the PAPAW more often upon leaving their homes. Subjects seemed to like the PAPAW's ease of use (85%), quick travel abilities in short or longer distances (29%) and the ability to climb hills easier (43%). They also rated the PAPAW as comfortable and easier to propel.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
		 More activities were accomplished in a day when using the PAPAW, as the subjects felt it was faster than their power wheelchair and it supplied relief when tired. With the PAPAW, subjects did not like battery location, height and weight of chair, lack of control over power levels and transportability.
Corfman et al. 2003 USA Pre-Post N=18	Population: Mean age: 34.5 yr; Gender: males=6, females=4; Level of injury: paraplegia=18; Chronicity=chronic. Intervention: Propulsion of a Quickie 2 manual wheelchair configured as a pushrim-activated power-assisted wheelchairs (PAPAW) and personal wheelchairs (PAPAW) and personal wheelchair on a dynamometer at 2 speeds and 3 resistance levels for 3 min per trial (minimal-0.9 m/s and 10 W; 1.8 m/s and 25 W; slight-0.9 m/s and 12 W; 1.8 m/s and 25 W; moderate-0.9 m/s and 14 W). Outcome Measures: Stroke pattern, Stroke frequency, Range of motion (ROM)-shoulder flexion/extension, abduction/adduction, internal/external rotation, horizontal flexion/extension- elbow flexion/extension, supination/pronation, ulnar/radial deviation.	 No stroke pattern difference was found between the two wheelchairs. Stroke frequency was different when comparing the two wheelchairs; however, this difference was dependent on speed (0.9 m/s or 1.8 m/s). During both of the slight trials and 0.9m/s moderate trial, shoulder flexion/extension ROM was decreased (p<0.05). During the 0.9m/s slight trial and 1.8 m/s normal trial, elbow and wrist flexion/extension ROM was decreased (p<0.05). Also, the wrist ulnar/radial deviation ROM was decreased during the 0.9m/s slight and moderate trials (p<0.05). With the exception of shoulder internal/external rotation, the PAPAW was accountable for reducing ROM values for all dependent variables
Cooper et al. 2001 USA Pre-Post N=10	 Population: Phase 2: Mean age: 35 yr; Gender: males=6, females=4; Level of injury: paraplegia=9, MS=1; Mean time since injury: 13 yr. Phase 3: Mean age: 45.2 yr; Gender: males=6, females=4; Level of injury: paraplegia=9, multiple sclerosis=1. Intervention: Phase 2-Propulsion of personal chair and pushrim-activated power-assisted wheelchairs (PAPAW) on dynamometer. Phase 3-Propulsion of personal chair and PAPAW through standardized activities of daily living obstacle course three times. Outcome Measures: Phase 2-Oxygen consumption, Ventilation, Heart rate. Phase 3-Performance on course; Completion time, Self ratings of comfort and ergonomics, Stroke frequency, Heart rate. 	 Phase 2: 1. Subjects using the PAPAW had lower oxygen consumption (VO2 mL/min, and VO2 mL/kg x min, p<0.001) and heart rate (p<0.05 in two conditions) when compared to their manual wheelchair use. 2. Oxygen consumption and heart rate, but not ventilation, were significantly different when comparing chairs and speed (p<0.001). Phase 3: 3. The PAPAW had a higher ergonomic evaluation than the manual wheelchair (p<0.01). 4. Subjects had faster completion times of the Activities of Daily Living (ADL) course (p=0.01) and had less difficulty over the large speed bump between trial 1 and 3 (p=0.02), when using the PAPAW as compared to the manual wheelchair. 5. The PAPAW had lower ratings on car transfer tasks of taking wheels off

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
		(p=0.004) and putting wheels back on (p=0.001).
Algood et al. 2005 USA Post-Test N=15	Population: Age range: 20-53 yr; Gender: males=11, females=4; Weight range: 45- 114 kg; Height range: 152-193 cm; Level of injury: tetraplegia=15; Time since injury range: 0.8-30.0 yr; Chronicity: sub-acute- chronic. Intervention: An obstacle course containing activities of daily life. Subjects used both their personal wheelchair and a pushrim-activated power-assisted wheelchairs (PAPAW) three times each. Outcome Measures: Heart rate, Completion time, Visual analog scale (VAS), Amount of assistance required.	 It was significantly easier for subjects to complete the obstacle course with the PAPAW, as compared to their own wheelchair (p<0.001). This was most apparent with the carpet, dimple strips, ramp incline and up curb cut obstacles (p<0.001). Completion time of the course, response to ergonomic questions and amount of assistance needed did not differ between wheelchairs. Mean heart rate was significantly lower in all three PAPAW trials when compared to the three personal wheelchair trials (p=0.015, p=0.001, p=0.003).

Summarized Level 5 Evidence Studies:

The following level 5 evidence studies have been reviewed, and the overarching findings from the studies are highlighted in this section. As noted at the start of this chapter, these types of studies are not included in the discussion or in the conclusions.

In a qualitative study, Giacobbi et al. (2010) gathered reported experiences from participants before, during, after use with a power assist wheelchair (PAW). 95% of participants reported that PAWs allowed greater access to diverse terrains that included sand, gravel and grass and made wheeling up inclines easier. 80% of participants reported general decreases in fatigue after using the PAWs. Participants reported that PAWs helped to improve mood and help with independence with respect to mobility. 65% of participants (13/20) reported that the use of PAWs was linked to participation in novel activities or those that were "out of the ordinary". Participants expressed that some of these were previous activities they couldn't participate in, for example, going to the flea market and zooming around, or playing ball in the yard with their dog.

Discussion

There were three randomized control studies that explored PAPAW use. Giesbrecht et al. (2009) studied eight participants (mixed diagnoses) who used both a manual wheelchair and a power mobility device (dual users) in their everyday activities in determining if a PAPAW would be an alternative to a power wheelchair (PWC) for community-based activities. The study results suggested that after introducing PAPAW, study subjects remained as active in their community and spent similar amount of time using the PAPAW instead of their PWC. It was interesting to note that on the Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST) Device subscale (outcome measure addressing activity level) the study participants rated four device subscale items higher for PAPAW use (weight, comfortable, dimensions, ease in adjusting) and four items higher for PWC use (durability, easy to use, safe and secure and effective). Study subjects identified that the PWC was preferred for outdoor activities and the PAPAW for tasks performed in a confined space. Only the self-esteem subscale (relates to emotional response and self-propulsion) on the Psychosocial Impact of Assistive Devices Scale (PIADS) was statistically significant between PWC and the PAPAW.

In the second RCT, Nash et al. (2008) tested the effects of PAPAW with respect to the energy needed and perceived effort required when wheeling a manual wheelchair for six minutes at a steady state and for twelve minutes with resisted wheeling at the study subject's greatest attainable speed. During the six-minute steady state and 12-minute resistive propulsion trials there was a significant increase in oxygen uptake (VO₂) at each time point for persons with paraplegia only. In addition, individuals with paraplegia travelled significantly farther than individuals with tetraplegia when using the PAPAW and both groups travelled farther with PAPAW than when using traditional wheels. Traditional wheels required greater energy cost than PAPAW and this increased the perceived exertion across all study subjects as the time component increased during the trials.

In the third RCT, Guillon et al. (2015) compared three different PAPAW (Servomatic A & B, and E-motion) to standard manual wheelchairs in a three phase study assessing wheelchair propulsion, indoor/outdoor use and ease of transferability in vehicles. Use of PAPAW resulted in greater decreases in oxygen consumption and heart rate compared to manual wheelchairs. But ease of transferability was greater when participants used manual wheelchairs compared to PAPAW. For the indoor and outdoor tests, the Servomatic PAPAW had better performance on completion time, pushrim frequency, and patient satisfaction compared to the E-motion PAPAW.

Corfman et al. (2003) examined the efficacy of the PAPAW in the reduction of upper extremity ROM and stroke frequency with nine individuals with paraplegia. When using the PAPAW upper extremity ROM was significantly reduced. The use of the PAPAW did not affect propulsion frequency. They suggest that the use of this device may reduce the frequency of upper limb injuries and allow an individual to use a manual wheelchair for a longer period of time.

Algood et al. (2005) compared the ability individuals to complete an obstacle course using a PAPAW and their own manual wheelchair. It was significantly easier for the subjects to propel on carpet, dimple strips, up a ramp as well as up curbs when using a PAPAW. Also, the mean heart rate was significantly lower. However, there was no significant difference in the time to complete the course, response to ergonomic questions or the amount of assistance required.

Cooper et al. (2001) compared the PAPAW to the subject's own wheelchair on a dynamometer and also through an obstacle course. On the dynamometer, subjects had lower oxygen consumption and heart rate when using the PAPAW as compared to their own manual wheelchair. Oxygen consumption and heart rate, but not ventilation was significantly different when comparing chairs and speed. On the obstacle course the PAPAW had a higher ergonomic evaluation than the manual wheelchair. Subjects had faster completion times with the PAPAW and less difficulty going over the speed bump. The PAPAW had lower ratings on car transfer tasks of taking wheels off and putting them back on.

Algood et al. (2004) investigated the differences in metabolic demands, stroke frequency and upper extremity ROM when propelling the PAPAW as compared to a regular manual wheelchair. Individuals propelled their own manual wheelchair and a PAPAW through three different resistances on a wheelchair dynamometer. Ventilation, oxygen consumption and upper extremity ROM was significantly reduced when using the PAPAW. Stroke frequency was reduced at low resistances. They also found that the PAPAW has the potential to reduce metabolic energy expenditure.

Fitzgerald et al. (2003) followed individuals for a period of four weeks, two weeks using a PAPAW and two using their own personal wheelchair. No significant differences were found

between the user's own wheelchair and the PAPAW for average and total distance traveled, velocity, or the number of times leaving the house. However, the subjects reported that they were more apt to use the PAPAW when leaving their house. The subjects also reported that the PAPAW provided relief when fatigued and that the wheelchair went faster (perception) resulting in accomplishing more in the day. The subjects rated the PAPAW with higher comfort and easier propulsion as compared to their own wheelchair.

Conclusion

There is level 4 evidence (from one pre-post test study; Corfman et al. 2003) that the use of a PAPAW will reduce upper extremity ROM in individuals with paraplegia during wheelchair propulsion.

There is level 4 evidence (from three pre-post test studies; Algood et al. 2005; Cooper et al. 2001; Fitzgerald et al. 2003) that use of a PAPAW may improve the ability of individuals with tetraplegia to use their wheelchair in a variety of environments and for typical activities.

There is level 4 evidence (from one pre-post test study; Cooper et al. 2001) that the use of a PAPAW may reduce metabolic energy costs for individuals with paraplegia during propulsion and has higher ergonomic rating by users.

There is level 4 evidence (from one pre-post study; Algood et al. 2004) that the PAPAW reduces upper extremity ROM in individuals with tetraplegia during wheelchair propulsion. Metabolic energy expenditure and stroke frequency may be reduced.

There is level 2 evidence (from one low level RCT study; Guillon et al. 2015) that PAPAW results in decreased oxygen consumption and heart rate compared to manual wheelchairs.

There is level 1b evidence (from one randomized controlled trial; Nash et al. 2008) that the use of PAPAW allows individuals with a spinal cord injury (paraplegia and tetraplegia levels) who have long standing shoulder pain to propel their wheelchair further while decreasing energy costs and perceived exertion.

There is level 1b evidence (from one randomized controlled trial; Giesbrecht et al. 2009) that for individuals requiring power mobility, the pushrim-activated, power assisted wheelchair may provide an alternative to power wheelchair use.

The use of power-activated power-assist wheelchairs (PAPAW) provide manual wheelchair users with paraplegia and tetraplegia with a less strenuous means of mobility, improve functional capabilities and reduce the risk of upper extremity injury.

3.3 Training

3.3.1 Wheelchair Propulsion Training
Wheelchair training is one of the eight key phases of for optimizing wheelchair service delivery outlined by the World Health Organization. For manual wheelchairs, there appears to be two distinct but related aspects of training in the literature; wheelchair skills training and manual wheelchair propulsion training. The former is covered in the Wheelchair Use section and relates to mastering management of the wheelchair in different situations and environments such as ramps, curbs, folding the manual wheelchair. The latter is reviewed in this subsection. Manual wheelchair propulsion is studied using kinetics and kinematics such as contact angle, stroke frequency and mechanical efficiency, to evaluate how to optimize manual propulsion, thereby affecting the potential risk for chronic overuse injuries related to propulsion. Propulsion training focuses on how these optimized techniques are translated into everyday use. The studies reviewed explore the delivery of this training and the effect of this type of training over time.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Zwinkels et al. 2014 Netherlands Review of published articles between inception to October 2013 N=21	Methods: Articles published in English focused on exercise training with at least one outcome measure for wheelchair propulsion (i.e., cardio-respiratory fitness, anaerobic capacity, muscular fitness, or mechanical efficiency). Databases: PubMed and EMBASE. Levels of Evidence: Moderate quality: Low quality RCTS, prospective controlled trials; Very low quality: Case Series, case reports. Questions/ Measures/ Hypothesis: To review the literature on the effectiveness of training programs on improving hand-rim wheelchair propulsion capacity.	 There was a total sample of 249 (50% SCI). For all studies examining interval training (n=8), endurance wheelchair propulsion capacity was found to significantly improve in the experimental groups (ranging from 18-34% in individuals with disabilities). In studies that reported sprint wheelchair propulsion (strength studies, n=2), strength training was not found to be effective in improving sprint performance. Overall, Mixed Training (n=6) studies were shown to improve endurance wheelchair propulsion. For the endurance studies (n=5), three studies reported significant improvement in endurance outcomes, two in peak oxygen intake, and only one study (with an able-bodied sample) showed significant improvement in mechanical efficiency.
Rice et al. 2013 USA RCT PEDro=6 N=27	Population: Mean age :40.0 yr; Gender: males=24, females=3; Level of injury range: L3-C7; Mean time since injury: 18.0 yr. Intervention: Compare 2 propulsion training methods (high and low tech) between experimental and control conditions to determine which system was more effective at teaching manual wheelchair users (MWUs) to increase contact angle (CA) and decrease stroke frequency (SF) during propulsion at two speeds (1.5 m/s or self-selected speed) on an overground course of 15m of level tile, of medium pile carpet and a 1.2° ramp. There were two experimental conditions: an instruction only (IO) group that received	 In controlling for velocity, weight, time since injury and level of injury: Both intervention groups showed increased CA and decreased SF in same day and 3 mo follow up compared to the CG (p<0.05); For SF, intervention groups decreased the identical amount but the IO group showed greater decrease at 3mo follow up (p<0.05); FB group showed greater percent increase in CA compared to IO group, who showed a greater percent increase than CG at both time periods (p<0.05); Both the FB and IO groups showed significant short-term increases in peak Fr at the handrim, with a larger percent

Table 10. Effect of Wheelchair Propulsion Training



	limb clinical practice guidelines by a physical and occupational therapist (IG); control group received standard therapy services (SCG). Outcome measures: Wheelchair setup, selection, propulsion biomechanics, pain, (numeric rating scale (NRS), Wheelchair Users Shoulder Pain Index (WUSPI) Satisfaction with Life Scale (SLS) and Craig Handicap Assessment and Reporting Technique scores. All measures completed at discharge, 6 mo and 1 yr.	2.	and 1 yr 100% of IG met the recommendation of an ultra-light wheelchair; 3) pain, immediate or long term (1 yr). In the SLS scores showed a trend for an increase in only the physical subsection between 6month and 1 yr (p=0.07) and the occupational subsection between 6mo and 1 yr (p=0.07). For propulsion biomechanics, compared to the SCG, the intervention group had significantly lower push frequency at discharge on tile (p=0.02) a trend effect on carpet (p=0.10) and used a significantly longer push length on ramps at all time points (p=0.03).
	Effect Sizes: Forest plot of standardized me	an di	ifferences (SMD ± 95%C.I.) as
	Rice 2014; Education on the Clinical Practi	ce Guio	sellne vs. standard Therapy Services
	MWC Propulsion - Tile		0.82 (0.11,1.53)
	MWC Propulsion - Carpet		0.65 (-0.06,1.35)
	NWC Propulsion - Kamp Push Length		0.38 (-0.31,1.08)
	WUSPI		0.28 (-0.41,0.97)
	-2 -1.5 -1	-(0.5 0 0.5 1 1.5 2
	Favours Contro	I	SMD (95%C.I.) Favours Treatment
Morgan et al. 2017 USA Prospective controlled trial N=6	Population: Mean age= 38±17.5 yr; Gender: males=4, females=2 ; Level of injury range: C6-L2. Intervention: Manual wheelchairs (MWC) users participated in nine 90-min wheelchair training sessions 2-3 times per week, using motor learning principleswith a repetition-based approach; participants acted as their own control The aim of the training was to increase the push angle and efficiency, use a semicircular push pattern and, decrease push force Two baseline measures were taken three weeks apart , and the psot-test immediately after the intervention Outcome Measures: Wheelchair push forces (WMS): Average force, Peak force, Slope of the force; Wheelchair Skills Test (WST), Kinematic Variables: Area of the push loop, hand-axle relationship, push angle; Wheelchair performance test (WPT): contact, recovery, speed, push	1. 2. 3. 4. 5.	Area of the push loop significantly increased from pre to post test (p=0.05), as well as hand-axel relationship (p=0.03). A positive, but not statistically significant improvement was found for push angle pre- and post- intervention (p=0.07). No significant improvement was found for the WST Three items on the WPT improved significantly pre and post intervention: recovery (p<0.01), speed (p<0.01), push effectiveness (p=0.04). Slope of the force was the only factor that improved significantly on the WMS (p=0.03).
Blouin et al. 2015 Canada Pre-Post N=18	Population: Mean age: 42.1 yr; Gender: males=16, females=2; Mean weight: 77.4 kg; Mean time since injury: 14.8 yr; Level of injury: C7 or LI; Severity of injury: AIS A, B or C. Intervention: Patients participated in a training session in a standard manual wheelchair on a stimulator with haptic biofeedback (HB) in order to modify patient's mechanical effective force (MEF)	1. 2. 3.	On average, participants increased mean MEF by up to 15.7% on right side and 12.4% on left side from pre- training to post-training. Power output was significantly higher during the training blocks compared to the pre-and post-training ($p \le .007$). Mean wheelchair velocities remained equivalent or slightly decreased during the training.

	along push phase to achieve more effective MEF pattern. Two pre- and two post training trials were completed without hepatic feedback, each for 1 min. Training was in five 3-min blocks with a 2min rest between; heptic feedback was provided at five different, randomized levels. Visual feedback on the linear velocity was also provided. Outcome Measures: Raw force measured using forces sensors on the wheels and simulator base and moment data measured using the SmartWheel, MEF (%push) patterns, mean wheelchair linear velocity, Mean biofeedback moments and mean power output.	 4. 5. 6. 7. 8. 	No significant differences in ΔMEF_{rms} scores were found neither between the pre-training and the training, nor between any pairs of training blocks (p>0.1). Biofeedback level had significant impact on mean MEF in both Q ₂ and Q ₃ quartiles and on both sides (p>0.02). Significant increases in mean MEF were found between the pre-training trial and training blocks BL3, BL4, and BL5 on the right side (p≤0.001). On the left side, mean MEF was significantly higher during training block BL5 in quartile Q ₂ , and demonstrated a tendency to increase between the pre-training trial and training blocks BL3, BL4, and BL5 in quartile Q ₃ (p≤0.06). Mean MEF decreased slight during post-training compared to pre-training on left side, remained equivalent on right side, led to non-significant
DeGroot et al. 2009 USA Pre-Post N=9	Population: Mean age: 37 yr; Gender: males=6, females=3; Injury etiology: tetraplegia=2, paraplegia=4, cerebral palsy=1, spinal muscular atrophy=1, multiple sclerosis=1; Mean during of w/c use: 10 yr. Intervention: Participants were trained on a wheelchair treadmill with verbal instruction (in-depth explanation of Boninger et al. propulsion principles – using a semicircular pattern, using long and smooth strokes and reducing push frequency) and visual instruction and feedback (1) video of an experienced wheelchair user demonstrating the four propulsion patterns – arc, single-loop-over, double-loop-over, and semicircular and 2) visual feedback of performance during propulsion)Training continued until trainer and trainee felt sufficient training and practice had occurred. 10 sec of data were collected immediately following training/practice. Outcome Measures: push frequency, push length, peak push force, average push force, peak push force and average speed using a SMART ^{wheel} attached to the participants' own MWC. Propulsion was on a wheelchair treadmill.	1. 2. 3. 4. 5.	 increase in ΔMEF_{rms}. Push length increased (p<0.05) pre-to post training. Push frequency decreased (p<0.01) pre-to post training. Peak (p<0.05) and average (p<0.01) forces increased pre-to post training. Average speed did not change. Graphic representations showed differences in propulsion characteristics between one participant with paraplegia and one participant with tetraplegia. Tetraplegia participant propelled at slower speed than paraplegia participant. Participant with tetraplegia had, on average, a lower push frequency than the participant with paraplegia. Push force comparisons did not show clear patterns.

Morgan et al (2017) explored the effectiveness of a repetition-based motor learning approach to improve propulsion techniques of longer strokes and changing the propulsion pattern to a

semicircular pattern. The training program was based on the recommendations to reduce force and frequency of pushes from Clinical Practice Guidelines for Preservation of Upper Limb Function Following Spinal Cord Injury. Participants all made some improvement in propulsion across all the testd variables, suggesting that this type of approach to improve propulsion techniques is viable; however, the number of participants effects the strength of the study and therefore the ability to generalize to other people.

Rice et al. (2013) compared two propulsion training methods to determine the effectiveness of training in relation to contact angle (CA) (angle along the arc of the hand rim), stroke frequency (SF) (number of strokes per unit of time), peak resultant force (Fr) (the maximum forces experienced during the push phase of propulsion), and peak rate of rise of resultant forces (rorF) (how rapidly the forces are applied to the hand rim). Testing was completed using two speeds (1.5 m/s and a speed the participant selected) and three over-ground conditions (tile, medium pile carpet and 1.2° ramp) over three training sessions. The findings suggest that there are immediate benefits to propulsion training with carryover of benefits long term (three months) as compared to the provision of opportunities to practice propulsion but without instruction (control group) regardless of the speed of propulsion or the type of surface used. It is worth noting however, the intervention groups also received weekly phone calls to remind them to continue to practice with the training techniques, the effect of which was not evaluated. Neither intervention required the presence of a health care professional; the multimedia presentation was a five-minute video and slide presentation emphasizing the importance of proper technique and defined the key parameters for monitoring such as CA. The second intervention group also received real-time feedback provided using a specialized wheel that collects data related to CA, SF, and velocity. This real-time feedback was projected onto a screen for the participant to view as they were propelling on the dynamometer. Variables were presented randomly and discontinuously in keeping with motor learning theory. It was noted that CA feedback was easier to react to than SF feedback and CA feedback had an inadvertent effect on SF as well.

Rice et al. (2014) examined if intervention that strictly adhered to the Clinical Practice Guidelines for Preservation of Upper Limb Function (Paralyzed Veterans of America) recommendations for wheelchair set up, selection and propulsion skills would decrease shoulder pain and improve satisfaction with life and participation as compared to standard care. Both the intervention group and the control group (standard care group) testing occurred on the same inpatient spinal cord injury rehabilitation program. Similar to Rice, et al. 2013, the intervention protocol also used a multimedia approach (printed material, DVD of propulsion skills and pictures) however different to the above study, therapists provided this training in addition to ongoing education and feedback related to the key concepts from the practice auidelines. All involved therapists received motor learning training in addition to training related to the practice guidelines. The significant findings from this study are fewer than the Rice et al. study; the findings of significance were a lower push frequency on tile at discharge from inpatients and a larger push length across all time points (discharge and six months and one year post discharge) for those who received the training compared to the control group who did not. However, the study did not find significance differences in pain with either pain scale used which differed from previous studies (identified within the article). Ongoing testing and follow-up over several years may be needed to determine if these findings persistent and if pain levels are impacted in the long term.

deGroot et al. (2009) examined the effects, both immediate and sustained, of a verbal and visual training intervention for manual wheelchair propulsion, comparing difference in effects on people with paraplegia versus people with tetraplegia. Researchers found that push length increased, and push frequency decreased immediately following training, however push forces

increased which was not expected. The authors questioned if this latter finding was an inadvertent result of participants focusing on the propulsion pattern, or a result of efforts to decrease push frequency, participants felt they needed to push harder. Comparison of findings for participants who had a paraplegia and tetraplegia found that push frequency (pushes per second) showed that participants with tetraplegia had a lower push frequency and a higher number of pushes to complete the same ten-meter distance. It is important to note that these comparisons were based on one participant for each group and that the total number of participants with paraplegia was four and two respectively.

Blouin et al. (2015) explored the influence of haptic biofeedback on mechanical efficiency propulsion training. Training was completed in five, three-minute training blocks with two one minute pre-and post testing blocks without the feedback. This group developed a simulator which provides feedback by increasing or decreasing the rolling resistance and therefore mechanical effort, as propulsion patterns deviate from or approached the desired pattern respectively. The authors cite that unrestricted increases in propulsion mechanical effective force (MEF) which has been associated with an increase in load at the shoulders, and mechanical inefficiency in propulsion. The authors suggest that through training with haptic biofeedback the MEF can be moderated therefore more efficient with less negative effect on the shoulders. They found that participants could modify their MEF pattern to become more efficient but only during the middle portion of the push phase where the greatest push effort occurred. They also found that the effects of the training were not sustained at post-testing by all participants.

Conclusion

There is level 1b (from one blinded RCT study by Rice et al. 2013; one RCT study by Rice et al. 2013; one prospective controlled study, Morgan et al 2017; and two pre-post studies by deGroot et al, 2009 and Blouin et al. 2015) evidence that wheelchair propulsion training result in improved biomechanics of propulsion which are sustained over time.

There is level 1b (from one blinded RCT study by Rice et al. 2013; one RCT study by Rice et al. 2013; and one pre-post study by deGroot et al. 2009) evidence that using a multimedia approach results in improved wheelchair propulsion training outcomes.

Propulsion characteristics of contact angle, stroke frequency and peak force at the handrim, all noted to be important to maintaining upper extremity health during propulsion, can be positively affected through w/c propulsion training.

Clinicians should consider incorporating a multimedia approach, such as video and verbal instruction with observational feedback, into wheelchair propulsion training particularly for people who are new to w/c use.

3.3.2 Physical Conditioning and Wheelchair Propulsion

Physical capacity is important to the development of wheelchair propulsion performance. Five articles have explored the relationship between physical conditioning and capacity, and wheelchair propulsion.

Author Year		
Research Design	Methods	Outcome
Score		
Total Sample Size		4 Oradiana a instant fiture or a standard
Gauthier et al. 2018 Canada RCT PEDro=5 N _{initial} =11 N _{initial} =9	age= 33.9 yr; Gender: males=3, females=1; Level of injury range: C7-T10; Mean time since injury: 6.0 yr. <i>MICT</i> <i>Group (n=5):</i> Mean age= 43.2 yr; Gender: males=3, females=1; Level of injury range: C6-T11; Mean time since injury: 15.5 yr. Intervention: Participants were randomized to a home-based self- managed manual wheelchair program. The high-intensity interval training (HIIT) group alternated 30s high-intensity intervals and 60s low-intensity intervals. The moderate- intensity continuous training (MICT) maintained a constant moderate intensity. The programs were six wks, consisting of three 40-min propulsion training session/wk. Outcome Measures: Cardiorespiratory Fitness: VO ₂ , Heart Rate (HR), PO _{peak} , RPE _{muscu} , RPE _{cardio} ; Upper Limb Strength:	 Cardiorespiratory intress outcomes improved, but not significantly between groups from pre- to post- intervention (p>0.05). Similarly, upper limb strength did not significantly improve between groups for all outcome measures (p>0.05). The results suggest that the HIIT program appears feasible and safe and has comparable effects on most cardiorespiratory fitness and upper limb muscle strength values versus the MICT program.
	Shoulder (flexors, extensors, abductors, adductors, internal rotators, external	
	rotators), Elbow (flexors, extensors).	
van der Scheer et al. 2016 USA RCT PEDro=7 N=29	 Population: Exercise Group (n=14): Median age= 55 yr; Gender: males=12, females=2; Level of injury range: C4-L5; Median time since injury: 16.0 yr. Control Group (n=15): Median age= 57 yr; Gender: males=10, females=5; Level of injury range: C4-L5; Median time since injury: 20.0 yr. Intervention: Inactive manual wheelchairs (MWC) users were randomized to exercise group, or no exercise. The low-intensity training program was 16wks, consisting of wheelchair treadmill propulsion 2x/wk for 30min. Outcome Measures: Peak aerobic work capacity: VO_{2peak}, PO_{peak}; Submaximal fitness: ME_{sub1}, ME_{sub2}; Anaerobic work capacity: 5s peak power output over a 15- m overground sprint (P5-15m); Isometric Strength; Wheelchair Skills Performance (WSP): performance time, ability score, strain score; Physical activity levels: Physical Activity Scale for Individuals with Physical Disabilities (PASIPD), distance. 	 Participants were, on average, able to increase power output and velocity over the training period. 10/14 participants felt that the training improved their fitness. Most participants reported that wheelchair skill performance and physical activity levels had not changed. No significant training effects were found in peak aerobic work capacity, WSP or Physical activity levels. P5-15m was the only outcome measure that was statically significant between the control and intervention group (p=0.02).
Torhaug et al. 2016	Population: <i>MST (n=9):</i> Median age=	1. MST significantly improved WE
Norway	42.0 yr; Gender: N/S; Level of injury range: T4-L1: Median time since injury:	compared to CG by 17.3%
Prospective Controlled	14.6 yr. CG (<i>n</i> =7): Median age= 47.1 yr;	significantly improved in MST group
N _{initial} =18	Gender: N/S; Level of injury range: T4-	compared to CG (p=0.007).
N _{final} =16	Intervention: In order to evaluate	between groups (p=0.96, p=0.9,
	wheelchair propulsion work economy (WE),	respectively.

Table 11. Physical Conditioning and Wheelchair Propulsion

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	participants either received maximal bench press strength training (MST), or to the control group (CG). MST group performed training 3x/wk, for 6wks, with 4 sets of four bench press repetitions. CG performed no formalized exercise routine. Outcome Measures: WE: Oxygen uptake (VO ₂), Pulmonary ventilation (VE), Respiratory exchange ratio (RER).	
Kilkens et al. 2005 Netherlands Cohort N=97	Population: Mean age: 38yr; Gender: males=74, females=24; Level of injury: paraplegia=73, tetraplegia=25. Intervention: Wheelchair Circuit test-eight standardized tasks in a fixed sequence on treadmill, hard and soft surface. Outcome Measures: Upper extremity strength through manual muscle testing (MMT), Peak oxygen uptake (VO ₂ peak), Peak power output (PO peak), Wheelchair Circuit ability, physical strain and performance.	 All physical parameters had significant improvements over time. PO peak improved between t1 and t2 and t2 and t3 (p<0.001). Maximum VO₂ peak improved between t1 and t2 (p<0.001) and t2 and t3 (p=0.046). MMT also improved between t1 and t2 (p=0.018), and t2 and t3 (p=0.014). Wheelchair circuit scores had significant improvements over time as well. Wheelchair circuit ability improved between t1 and t2 (p<0.001) and t2 and t3 (p=0.013). Performance time also improved between t1 and t2 (p<0.001) and t2 and t3 (p=0.002). Physical strain improved between t1 and t2 and t3 (p=0.001).
Qi et al. 2015 China Pre-Post N=11	Population: Mean age: 42.1 yr; Gender: males=8, females=3; Level of Injury: paraplegia (T6-L1)=11; Severity of injury: AIS A=8, AIS B=1, unspecified=2; Mean time since injury: 10.4 yr. Intervention: Patients completed three sets of 3 min wheelchair propulsion trials at different speeds; a self-selected comfortable speed, 1 ms, 1.3 ms and 1.6 ms with a 5 min rest period between each trial. After a 15 min break, patients then completed a graded exercise trial at a constant speed of 1 ms with a work load set at 10 W and increasing by 5 W every 1 min until exhaustion. Outcome measures were performed during each trial with perceived rate of exertion for respiration and for local shoulder and arms exertion. Outcome Measures: Ratings of perceived exertion (RPE) according to 15-point Borg Scale, Oxygen uptake (VO ₂), Carbon dioxide output (VCO ₂), Heart rate, Ventilation volume.	 Propulsion at 1.6 ms resulted in significantly higher levels of VO₂ Peak output, RPE Respiration and ventilation volume compared to propulsion at 1ms and at self-selected speed (all p<0.05). No significant differences were found between RPE Respiration and Arm Exertion at different VO₂ Peak levels during the graded exercise trial. No significant differences were reported between trials for RPE Respiration and RPE Arm Exertion.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
de Groot et al. 2007 Netherlands Pre-Post N=80	Population: Mean age: 39.4 yr; Gender: males=61, females=19; Mean weight: 72.9 kg; Level of injury: tetraplegic=18, paraplegic=62. Intervention: Patients with SCI were tested with wheelchair exercise tests at start of inpatient rehabilitation (T1), 3 mo post (T2), at discharge (T3) and 1 year after rehabilitation (T4) to determine whether mechanical efficiency (ME) relates to wheelchair propulsion capacity and wheel chair performance tasks. Testing was done in a standard w/c, and included two 3 min submaximal steady state w/c exercises on treadmills, a peak aerobic test and four standardized w/c performance tasks (figure-of-eight, 15 m sprint, propelling on a treadmill with 3% slope, propelling on a treadmill with 6% slope for 8 sec. Outcome Measures: Energy expenditure (En), Respiratory exchange ratio (RER), Mechanical efficiency (ME), Peak power output (POpeak), Performance time score and physical strain score.	 ME showed a significant relationship with PO_{peak} (p≤0.002) where a 1% higher ME related to a 1.6-2.2 W higher PO_{peak}. A significant relationship was found between the ME and POpeak, and the sum of performance time in exercise block 2 only of the sum of the performance time of a 15-m sprint and for figure-of-eight in exercise block 2 only (p=0.02) when correcting for lesion level, VO2_{peak}, ME was not related to the physical strain (%HRR, calculated for the 3% and 6% slope tests) at either one of the two exercise blocks (B1: p=0.56; B2: p=0.85).
Dallmeijer et al. 2005 Netherlands Pre-Post N=132	 Population: Mean age: 39.4 yr; Gender: males=100, females=32; Mean weight: 72.9 kg; Level of injury: tetraplegic=37, paraplegic=95; Mean time since injury 269 days. Intervention: Patients were investigated at start of active rehabilitation (T1), 3 mo (T2) and end of clinical rehabilitation (T3) to describe the course of wheelchair propulsion capacity (WPC). WPC was measured as maximal power output achieved in a maximal wheelchair exercise test on treadmill. Outcome Measures: Maximal power output (PO_{max}). 	 The mean (modeled) PO_{max} for the whole group was 30.6 W at t1, and 39.3 W and 44.3 W, at t2 and t3, respectively (p=0.000). POmax increased significantly between t1 and t2 *8.7 W; 28%) and between t1 and t3 (13.7 W; 45%). Persons with paraplegia had (on average) a 21.9W higher PO_{max} than persons with tetraplegia (β=21.9) (p=0.000). Persons with incomplete lesions had (on average) a 5.4 W higher PO_{max} than persons with complete lesions (β =5.4) (p=0.043). Changes in POmax depend on age and gender; younger (β=-0.254) (p=0.026) and male persons (β=7.235) (p=0.021) showed larger increases in POmax than older and Females participants. The inability to perform the test at t1 was controlled; this control variable was highly significant, showing on average a 14.5 W (p=0.000) lower POmax for subjects who were not able to perform the test at t1 compared with those who were able to do so.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Rodgers et al. 2001 USA Pre-Post N=19	Population: Mean age: 44 yr; Gender: males=16, females=3; Mean height: 174.5 cm; Mean weight: 79.1 kg; Injury etiology: SCI=15, spina bifida=1, multi-trauma=2, bilateral tarsal tunnel syndrome=1; Mean duration of manual w/c use: 17 yr. Intervention: Participants who were manual wheel chair users >1 yr took part in supervised therapeutic exercise (strengthening of posterior deltoids, infraspinatus, teres minor, rhomboids, middle trapezius, erector spinae, biceps and wrist extensors muscles, stretching and aerobic exercise using w/c seated rowing machine) 3x/wk for 6 wk. Pre- and post-tests included 1) a maximal graded exercise test (GXT) where participants rested for 6 min, then propelled for 3 min at a rate to 3 km/h after which a load of 0.3 kg was added every 3 min until the rate of propulsion could no longer be maintained and 2) a fatigue test which was the same as the GXT except the load added was the maximum load; participants propelled until volitional exhaustion. All pre-post testing was completed on a prototype w/c ergometer with 22" hand rim and no wheel camber. Outcome Measures: Handgrip strength (average of 3 measures of dominant hand), heart rate, exercise load changes, kinetic and kinematic data using 3 Peak 3D CCD camera and video system, a PY6-4 force/torque transducer, a potentiometer and a 3D-linked segment model, handrim kinetics, propulsion temporal data, Oxygen Update (VO ₂), Metabolic Economy.	 Exercise load significantly increased for all strengthening activities (p<0.01). Handgrip strength measures were unchanged. Wheelchair propulsion stroke frequency significantly decreased following training (p=0.039) as well as power output (p=0.012). Significant increase with training in shoulder flexion/extension (p=0.013), maximum elbow extensions (p=0.03) and trunk flexion (p=0.001). Of wheelchair kinetic measures, only propulsive moment (Mz) significantly increased with training (p=0.010), showing 14% improvement in propulsive moment. Wrist extension only joint kinetic measure to significantly increase after training (p=0.033). Trunk flexion/extension ROM and wrist flexion moment both significantly increased with fatigue following training (p<0.05).

Kilkens et al. (2005) investigated the longitudinal changes in manual wheelchair skill performance and parameters for physical capacity of people with SCI at the beginning of their inpatient rehabilitation, at three months and at point of discharge. The wheelchair circuit consisted of eight standardized tasks in a fixed sequence on a treadmill, hard and soft surface. The physical capacity parameters included upper extremity muscle strength, peak oxygen uptake and peak power output (PO peak). Their study found a significant relationship between upper extremity strength and PO peak as parameters of physical capacity that influence wheelchair propulsion performance during inpatient rehabilitation of individuals with SCI.

Dallmeijer et al. (2005) tracked 132 participants across eight SCI rehabilitation centres to describe the changes that occurred in relation to wheelchair propulsion capacity (WPC) from the start of rehabilitation, three months post and at discharge. An overall improvement of 45% in WPC, as measured by Maximum Power Output (POmax) was found over the full course of

rehabilitation, with significantly higher POmax being noted for participants with incomplete lesions, participants who were younger, and participants who were male. The authors suggest that these findings can help guide clinical intervention related to WPC, individualizing intervention based on these characteristics. However, the course of intervention related to WPC during rehabilitation was not described; it is unclear if there was a standard approach to intervention.

deGroot et al. 2007 examined mechanical efficiency (ME) of wheelchair propulsion, of people with SCI at the start of their rehabilitation, three months post, at discharge and one year post discharge. They are hypothesizing that higher mechanical efficiency, which they attributed to an improved propulsion technique, would show higher peak power outputs (POpeak), better performance times and lower percentage heart rate reserve (%HHR). They found that ME was significantly related to wheelchair propulsion capacity as measured by POpeak, and to the performance time of two wheelchair performance tasks, during rehabilitation and one year post discharge. The authors attributed the higher ME indirectly to propulsion technique, but no data was presented related to participants' propulsion technique.

Rodgers et al. (2001) hypothesized that a program which combines stretching and strengthening of the muscles critical to propulsion as well as aerobic training would result in more efficient wheelchair propulsion. The supervised training program was completed three times per week for six weeks. Pre and post testing found the only significant wheelchair kinetic change was the propulsive moment, which represented a 14% improvement. The authors suggest that this finding in conjunction with the lack of change noted in the hand rim peak forces and a significant decrease in stroke frequency indicate biomechanical efficiency was improved without increasing stresses on the upper extremity joints. The authors suggest that the findings of significant increases in three kinematic measures (shoulder flexion/extension, maximum elbow extension and trunk flexion) can augment propulsion, especially at times of fatigue.

Qi et al. (2015) explored the relationship between perceived rate of exertion and physical capacity during typical mobility activities. Eleven people with a spinal cord injury level lower than T6 completed propulsion testing on a treadmill in their own wheelchairs, at three specified rates of speed which the authors equated to three different mobility activities; a self-selected comfortable speed at 1ms equated to the minimal safe speed to cross a street with traffic lights, 1.3 ms equated to typical able bodied walking speed, and 1.6ms equated to the upper limit of a self-selected speed. A final test of propulsion was completed using the first test speed with increasing resistance until exhaustion. The authors found that most participants chose a propulsion speed of 1.1 ms as a comfortable speed, which corresponded to approximately 53% VO_{2peak} and an average heart rate of 104 beats per minute (0.69% HR_{max}). They also found that there were no significant differences between the rate of perceived exertion for respiration and arm. The authors indicate these findings suggest that self-selected propulsion speeds of low and moderate rates, which correspond to typical daily life mobility activities, can provide cardiovascular conditioning.

Gauthier et al, 2018 compared the feasibility, safety and preliminary effectiveness of homebased high intensity interval training (HIIT) and moderate intensity continuous training (MICT) programs in eleven manual wheelchair users with spinal cord injury. Despite the absence of significantly significant cardiovascular and upper extremities strength changes, most participants indicated considerable subjective improvements in general health, including cardiorespiratory fitness and all would recommend their program to others with SCI. The authors noted statistically significant improvements in VO2peak in two individuals in the MICT group who were not regularly exercising prior to the training. It was suggested that training could have the biggest impact in sedentary participants as it was the least active individuals at baseline who showed the greatest improvements in UE muscle strength. One participant in the HIIT group dropped out due to shoulder pain and another reported a significant increase. With weekly telephone follow-ups, both training programs were determined to be feasible and safe in the community, but it is noted that programs should be individualized and attention paid to the potential development of shoulder pain with a HIIT, especially in participants with pre-existing shoulder pain.

van der Scheer et al. 2016 investigated the effects of a low-intensity wheelchair training program in a group of 29 inactive individuals who had been living with spinal cord injury greater than ten years. Some research has shown that although higher intensity wheelchair training can be more effective, it may lead to lower adherence, dropout or injuries and when exercising at a lower-intensity, studies have shown that increased frequency is needed to create an exercise effect. Considering that, the authors in this study wanted to learn whether a low-intensity program with a frequency of twice weekly was enough to improve cardiovascular and propulsion outcomes. The results showed no significant training effects between the exercise and the control group in any of the measures, with the exception of the sprint power outcome. However, it was queried whether this positive result may have been due to a relative decline in the control group. The authors concluded that this dosage of exercise is insufficient for substantial improvements in an inactive population with long-term SCI.

Torhaug et al 2016 investigated the effect of maximal bench press strength training on wheelchair propulsion work economy (WE), in a group of individuals with paraplegia. Post testing results showed a 16% improvement in 1RM strength resulting in a 17.3% improvement in WE during wheelchair ergometry, as indicated by a reduction in in VO2 consumption. The authors suggest that a strength training regime of high load and few repetitions can lead to improved mobilization force during the concentric phase of wheelchair propulsion, and, despite no endurance-training component to the intervention, result in lower oxygen cost and more efficient wheelchair work economy. Two participants

withdrew from the study because of shoulder pain and the authors recommend beginning the training at a lower intensity in those with any latent shoulder disease.

Conclusion

There is level 2 evidence (from one cohort study; Kilkens et al. 2005; from two pre-post study; deGroot et al. 2007; Rodgers et al. 2001) that exercise training (at physical capacity) and upper extremity strengthening influence wheelchair propulsion performance during and beyond inpatient rehabilitation.

There is level 4 evidence (from one pre-post study; Qi et al. 2015) suggesting that manual wheelchair propulsion at low (1ms) and moderate (1.3ms) propulsion rates during typical daily life mobility activities contribute to cardiovascular conditioning.

Level 2 (Gauthier et al 2018) evidence that community-based programs are feasible and safe training programs for manual wheelchair users, but attention needs to be paid to the potential development of shoulder pain particularly with a high intensity interval training program.

Level 1 evidence (from one randomized control test study; van Der Scheer et al 2016) suggests that a twice weekly low-intensity wheelchair propulsion exercise is not adequate enough to lead to significant improvements in fitness and wheelchair propulsion activities, skill, capacity or performance in inactive manual chair users with long-term SCI.

Physical conditioning and strengthening of the upper extremity is important to the development of wheelchair propulsion capacity; it should begin at initial rehabilitation.

High intensity training activities can create an increased risk for shoulder pain in those with latent shoulder impairments or pain.

3.4 Wheelchair Use

Wheelchair use is examined from different perspectives, using various factors to explore how wheelchair use is influenced, ultimately to increase participation and quality of life. The research literature in this area is broad based, diverse, often overlapping and primarily focuses on manual wheelchair use. The first subsection explores the characteristics of wheelchair use in daily life. The second subsection focuses on participants' satisfaction with their wheelchair and its performance. The third subsection expands on the satisfaction but from the perspective of how repairs, accidents, falls and these potential adverse consequences affect wheelchair use. The final section related to wheelchair use is that of wheelchair skills.

3.4.1 Wheelchair Usage

In the wheelchair usage section, the majority of studies are surveys, descriptive studies, or have used cross-sectional analysis to interpret results, therefore have a level 5 evidence rating. It is felt that these studies have novel and important observations to offer the reader; for these

reasons they have been left in the body of this section and not summarized. Studies have explored different factors related to wheelchair use and participation and examined the gender differences in shoulder strength as it relates to propulsion and therefore wheelchair use.

Author Year Country Bosoarch Docign	Mothods		Outcome
Score Total Sample Size	methous		
Karmarkar et al. 2011 USA Pre-Post N=39	Population: Mean age: 62.5 yr; Gender: males=37, females=2; Level of Injury: cervical=12, thoracic=11, lumbosacral=4, other=11; Mean time since injury: 29.4 yr. Intervention: Participants' wheelchairs were fitted with a customized data-logging device to measure mobility during the National Veterans Wheelchair Games (NVWG). Outcome Measures: Wheelchair-related mobility variables.	1.	Both the manual wheelchair (MWC) and power wheelchair (PWC) participants had significantly higher mobility during the NVWG, compared to in their home and community, regarding distance traveled (MWC p<0.001, PWC p=0.004), wheelchair propulsion velocity (MWC p<0.001, PWC p=0.002), continuous wheelchair drive distance (MWC p<0.002, PWC p=0.006) continuous wheelchair drive time (MWC p<0.001, PWC p=0.005), number of stops every 500m (MWC p<0.001, PWC p=0.002). There was no significant difference in MWC and PWC groups in number of events participated for all sports activities (p=0.12).
Tsai 2014 USA Case Series N=2986	Population: Mean age: 40.0 yr; Gender: males=2362, females=623; Severity of injury: AIS A/B=2529 C=457; Mean time since inury: 6 yr. Intervention: Data was gathered from the National Spinal Cord Injury Database (NSCID). Participation and employment status were assessed from follow up interviews. Initial interviews were conducted on SCI patients from 18 centers of the Model Spinal Cord Injury System in the US from 2004-2010. Outcome Measures: Craig handicap assessment and reporting technique-short form questionnaire (CHART-SF) and employment status to measure social participation, and evaluate the association with type of mobility device used (manual w/c; externally powered wheelchair (i.e., power w/c, or power assist wheels) and driving vehicle).	 1. 2. 3. 4. 5. 6. 	Positive correlations noted between using an externally powered wheelchair and age, age at injury, being Females, higher injury level and having an indwelling catheter. Negative correlations were observed between using an external powered wheelchair and being employed, AIS A/B, upper limb strength, and FIM scores. Positive correlations were observed between using a modified vehicle and being employed, AIS A/B, upper limb strength, FIM scores, and years since injury. CHART-SF and likelihood of employment were negatively correlated with age, age at injury, using an external powered wheelchair, having a catheter indwelling in the bladder, and pain. CHART-SF and likelihood of employment were positively correlated with years since injury, using a modified vehicle, upper limb strength, using intermittent bladder catheterization, and FIM scores. CHART-SF and employment were positively correlated with using a modified vehicle compared to not possessing or driving a modified vehicle.

Table 12. Characteristics of Wheelchair Usage

Author Year Country Research Design Score Total Sample Size	Methods		Outcome
		7. F v t f c	Participants who used a modified vehicle had approximately: 2 days more out of home per wk, two more business associates, and 1 additional riend contacted at least once a mo compared to participants not bossessing a modified vehicle.
Pettersson 2015 Sweden Observational N=48	Population: Median Age: 64 yr; Gender: males=33, females=15; Level of injury: tetraplegia=26, paraplegia=22. Intervention: All participants were administered a Swedish aging with a spinal cord injury study (SASCIS) specific questionnaire. Outcome Measures: SASCIS: Patient characteristics, Environmental barriers and accessibility component of the Housing Enabler assessment, Impact on participation and autonomy (IPA) assessment.	1. F (r 2. c f f 7 3. F 7 3. F 7 4. F 5. F 5. F 6. F 6. F	Patients with powered mobility devices PMD) used their device significantly more for outdoor and indoor use compared to just outdoor (p<0.0005). Patients who used their PMD's putdoors only had a significantly lower unctional limitation due to a prevalence of reduced fine motor skills compared to those who used their PMD's indoor and outdoor (p=0.009). Patients who used their PMD's putdoors only had a significantly lower unctional limitation due to a prevalence of poor balance compared o those who used their PMD's indoor and outdoor (p=0.018). Patients who used their PMD's indoor and outdoor (p=0.018). Patients who used their PMD's putdoors and those who used their PMD's outdoors and indoors listed the same 3 environmental barriers as generating the most accessibility problems (mailbox, high hreshold/steps, and wall-mounted cupboards/shelves). Patients reported fewer autonomy restrictions present indoors compared o outdoors. Patients reported the greatest autonomy restriction for going on trips and vacations when one wants.
Phang et al. 2012 Canada Observational N=54	Population: Mean age: 47.7 yr; Gender: males=43, females=11; Level of injury: paraplegia=41, tetraplegia=13; Level of severity: complete=27, incomplete=27, AIS: A=27, B=1, C=15, D=11, E=0. Intervention: Participants completed a questionnaire. Outcome Measure: Leisure Time Physical Activity, Wheelchair Skills Test (WST), Wheelchair-use self-efficacy.	1. T re a w b 2. T re s a	here was a significant positive elationship between wheelchair skills nd leisure time physical activity, and wheelchair-use self-efficacy (p<0.05 for oth). There was no significance in the elationship between wheelchair-use elf-efficacy and leisure time physical ctivity (p>0.05).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Oyster et al. 2011 USA Observational N=132	Population: Mean age: 39.4 yr; Gender: males=106, females=26; Level of injury: paraplegia=94, tetraplegia=38; Mean time since injury: 11.2 yr. Intervention: Participants completed a questionnaire, and were fitted with a custom-designed data-logging device on their wheelchair to monitor their routine daily activities. Outcome Measures: Craig Handicap Assessment Recording Technique (CHART), Wheelchair mobility.	 Age was significantly related to wheelchair mobility (p=0.01). Body Mass Index and duration of injury, level of SCI, income, education, and sex were not found to be related to wheelchair mobility. Participants who used ultralight-weight manual wheelchairs had significantly improved wheelchair mobility (p=0.05) compared to other types. According to CHART sub-scores, duration of injury, physical independence, and occupation were significantly correlated to mobility (p<0.05).
Cooper 2011 USA Observational N=16	Population: Mean age: 49.1 yr; Gender: males=15, females=1; Level of injury: tetraplegia=9, paraplegia=7; Type of w/c used: manual wheelchair (MWC)=7, power wheelchair (PWC)=9; Mean time since injury: 18.9 yr. Intervention: A survey (PARTS/M) was administered to SCI participants who were participating in the National Veteran's Wheelchair Games to capture frequency of community participation in the areas of leaving home, transportation, active recreation, leisure activities, and socializing. A data logging device was attached to each participant's own wheelchair, which recorded their wheelchair activities in their community environment for 2 wk (distance travelled, speed, number of stops and drive time). Outcome Measures: Participation survey/mobility (PARTS/M) questionnaire; movement activity from data logger.	 Subjects travelled an average distance of 3374.07±1677.22 m at an average speed of 0.77±0.17 m/s. Subjects stopped an average of 146.73±91.96 times per day. Subjects drove an average of 68.65± min/d with a range of 11 to 107 min Community participation were calculated for only 14 participants due to missing data; scores averaged at 11.98±2.98. For MWC there was a significant positive correlation between average speed travelled and the community participation areas of transportation (r1 =.837, p=0.19, p<0.05) and socialization (r1=.772, p=0.042, p<0.05); there was also a trend towards a correlation between average speed travelled and total community participation scores (p<0.10). For PWC there was a trend towards significance between average speed travelled and leisure activities (r1=.636, p-0.006). No significant differences between wheelchair types were observed in regard to distance travelled and community participation.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome	
Hatchett et al. 2009 USA Observational N=67	 Population: Mean age: 35 yr; Gender: males=60, females=7; Level of injury: paraplegia=67; Mean time since injury: 9.9 yr. Intervention: Analysis to determine impact of gender on shoulder muscle strength and community wheelchair (WC) usage in individuals with paraplegia. Outcome Measures: Maximal isometric peak torque measured using a Biodex System 3 Pro dynomometer, Shoulder flexion, Extension, Abduction, Adduction, Internal rotation, External rotation using a lever which participants pushed or pulled, Community WC usage was measured using the Topeak® bicycle odometer system. 	 There was a significant difference in normalized shoulder torque between men and women where women were 62%–96% weaker than men (p<0.0001). In both men and women, the shoulder adductors were the strongest muscle group (men=46.8 N·m/kg, women=28.0N·m/kg), followed by the shoulder extensors (men=44.6 N·m/kg, women=27.4 N·m/kg). Shoulder external rotators were the weakest muscle groups (men=21.7 N·m/kg, women=12.6 N·m/kg). Significant difference in the average daily distance traveled in the community, with men propelling their WCs 3.1±1.7 km/day and women propelling 1.8±1.2 km/day (p<0.05). In post hoc analysis, strongest predictor of average daily distance travelled was normalized external rotation torque (<i>R</i>=0.368, <i>R</i>²=0.136, p=0.008). No significant difference in average velocity of propulsion between men and women (55.9±14.8 m/min and 48.7±9.2 m/min, respectively). 	
Tolerico 2007 USA Observational N=52	Population: Mean age: 46.8 yr; Gender: males=47, females=5; Injury etiology: SCI=40, muscular dystrophy=1, multiple sclerosis=5, post polio syndrome=1, TBI=1, Guillain-Barre syndrome=1, amputation=3; Range of duration of w/c use: 1-45 yr. Intervention: A datalogger attached to participants' primary manual wheelchair tracked distance propelled, speed propelled, occupancy during the National Veteran's Wheelchair Games and an additional week in their home environment following the games for a total of either 13 or 20 days. Demographic information was gathered by survey. Outcome Measures: Demographic survey including items for age, type of injury/disability, race/ethnicity, gender, type of wheelchair; for the 2 nd and 3 rd years questions about employment status, ability to use transportation independently, body weight, primary residential setting, feelings on accessibility and satisfaction with primary wheelchair was added. Movement data from data logger included	 98% (n=51) of participants used ultralightweight wheelchairs Subjects travelled an average distance of 2457.0±1195.7 m at an average speed of 0.79±0.19 m/s for an average of 8.3±3.3 hr/day. Subjects accumulated an average of 47.9±21.4 min/day of movement with their primary wheelchair in a home environment over the day. No significant differences in mobility characteristics, activity levels and level of SCI There was a significant difference in speed, distance and duration during an average day at the games compared to at home (p<0.001). Patients' employment status was significant associated with the average distance travelled (p=0.002), average accumulated min/day (p=0.006), and maximum daily distance travelled between consecutive stops (p=0.01). Patients reported an average body mass of 85.4±16.0 kg, which did not correlate to mobility characteristics or activity levels. No significant differences were observed in the patients' residential 	

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
		setting, satisfaction with primary wheelchair, and perceived influence of community on activities when compared with mobility characteristics and activity levels.
Chaves 2004 USA Observational N=70	Population: Mean age: 41 yr; Gender: men=55, women=15; Level of injury; tetraplegia=29, paraplegia=38; Mean time since injury: 14 yr. Intervention: A survey was administered to SCI participants discharged from two major rehabilitation centres, one in Pittsburgh (Pitts) and one in St, Louis (SL). Outcome Measures: Participation survey/mobility (PARTS/M) questionnaire using 3 of the 25 major life activities: 1) moving around inside the home which including getting in/out of bed, of the wheelchair and going from room to room2) leaving the home and 3) transportation including accessing and using different forms of transportation.	 95% (n=38) of participants with paraplegia used manual wheelchairs; 55%(n=29) of people with tetraplegia used power wheelchairs Participants with paraplegia perceived pain as a limiting factor for transportation use significantly more than people with tetraplegia (tetra=3%, para=21%, p=0.047). There was a trend towards a lack of equipment being a limiting factor for transportation use for people with tetraplegia more so than for people with paraplegia subjects (tetra=7%, para=3%, p=0.099). Significant differences were seen between the two test sites with regards to: 1) the type of wheelchair used (p<0.05) where Pitts used more manual wheelchairs (Pitts=87%, SL=67%) and SL used more power wheelchairs (Pitts=13%, SL=33%), 2) A greater percent of SL participants reported wheelchair seating (Pitts=5%, SL=24%, p=0.0285), social attitudes (Pitts=0%, SL=18%, p=0.007), and self-concept (Pitts=0%, SL=15%, p=0.015) as limiting factors for leaving the home; 3) Significantly greater percent of SL patients reported social attitudes as a limiting factor for transportation (Pitts=0%, SL=15%, p=0.017).

Oyster et al. (2011) explored manual wheelchair use by 132 people who had a spinal cord injury. They compared average daily distance travelled, speed traveled, and amount of time spent moving in a wheelchair (distances greater than 15 m) to participant demographics and to the Craig Handicap Assessment and Reporting Technique (CHART) subscales of social integration, mobility and occupation. Findings suggest that younger people with SCI travel faster than older counterparts but not significantly further. The average distance travelled was 1877 meters with a standard deviation of 1131, suggesting greater variability in the range of distance travelled. However, the average amount of time spent moving more than 15 meters in the wheelchair was on average 47 minutes per day. The authors suggest that the moderate correlation between wheelchair mobility metrics (distance and speed) and the CHART total score and scores on mobility is indicative that the CHART is capturing different aspects of participation than mobility metrics. The authors did not report on the average amount of time

spent in the wheelchair compared to the time moving in the wheelchair. It is however, reasonable to assume that participants would have been in their wheelchairs for at least double the recorded time moving, which raises the question of what participation is occurring while stationary in the wheelchair, or in conjunction with the movement less than 15 meters, that were eliminated from this study.

Cooper et al. (2011) investigated the correlations between the mobility characteristics of distance travelled, speed, number of stops, and drive time, and frequency of participation in community activities areas of leaving home, transportation, active recreation, socialization and, leisure activities. Researchers recruited participants from the National Veteran's Wheelchair Games, with a final 16 participants consenting to completing the PARTS/M guestionnaire to gather community participation data and having a data-logger attached to their wheelchair for two weeks to gather the mobility characteristics data. Data for both manual and power wheelchairs were gathered. Findings indicated that on average participants travelled 3,374 meters per day, at an average speed of 0.77 meters per second, for an average driving time of 68.65 minutes a day, stopping an average of 146 times per day. A stop was determined when no mobility activity occurred for more than seven seconds; the authors did not provide reasoning for this decision. Significant correlations between average speed travelled and community participation areas of transportation and socialization, for participants who used manual wheelchairs. A trend towards significant correlation was found between community participation area of leisure activities and speed travelled for participants who used power wheelchairs. The authors identified a limitation of their study was that the data logger did not differentiate between home mobility and community mobility and that the community participation areas chosen from the PARTS/M questionnaire were limited to those where participants would be outside of the home. It is also interesting to note that the average driving time was 68.65 minutes per day, which is just over an hour a day; the range was 15.72 to 107.45 minutes per day which when considered over the course of a full day, it raises the question of what activities are people participating in that does not require mobility during the majority of their day.

Tolerico et al. (2007) observed the mobility characteristics of people with SCI who use manual wheelchairs in two different environments; the first was their residential setting and the second the National Veteran's Wheelchair Games (NVWG). Recruitment occurred at these games for three subsequent years, June 2004 until July 2006. The study results indicated that participants were significantly more active during the games time period than when they were at home; average distance was $6,745.3\pm1,937.9$ meters at 0.96 ± 0.17 meters per second for 12.4 ± 1.7 hours per day compared to an average distance of $2,457\pm1,195.7$ meters at a speed of 0.79 ± 0.19 meters per second for an average of 8.3 ± 3.3 hours per day at home. The authors suggest these findings suggest that people are more active when the environment promotes activity, however, even people who participate in these games, are less active at home by almost half; they even spend less time in the wheelchair.

Karmarkar et al. (2011) observed the mobility patterns of adults over the age of 50 over 5 days during the National Veteran's Wheelchair Games (NVWG) and compared them to patterns over a two-week period in their home environment. Not surprisingly, the results indicated that regardless of type of wheelchair used, people were more active during the NVWGs than at home. The authors report that the secondary analyses indicate that age negatively affects MWC propulsion velocity but positively affects PWC driving velocity. The authors suggest that their findings support the use of data loggers to examine mobility patterns in the community as well as support that variation in wheelchair use exists depending on the environment therefore further research into this area is needed to fully understand wheelchair use.

Phang et al. (2012) proposed that a contributing factor to the low Leisure Time Physical Activity (LTPA) identified in previous studies may be related to wheelchair skills and therefore selfefficacy. Therefore, the purpose of their study was to determine whether self-efficacy could account for the relationship between wheelchair skills and LTPA in people with SCI. The authors suggest that their findings of a significant relationship between wheelchairs skills and LTPA is consistent with other study results, but the modest size of the relationship suggest other factors in addition to wheelchair skills affect LTPA. The authors also suggest that due to their study design that it is not possible to conclude that better wheelchair skills lead to greater LTPA or vice versa. They do however, suggest that insight into why people with better skills may be more inclined to participate in physical activities can be gained from their results that indicate 50% of the relationship between wheelchairs skills and LTPA were explained by barrier-free self-efficacy. They offer that having better wheelchair skills may bolster self-efficacy to overcome barriers to participation. Interestingly, wheelchair use self-efficacy was found to not be a mediator of the wheelchair skills - LTPA relationship, however, the scores of the wheel-con used for wheelchair use self-efficacy were high, potentially affecting the ability to detect changes. The authors suggest that further research is needed to determine the role of wheelchair skills, in wheelchair use and in overcoming barriers to physical activity participation.

Tsai et al. (2014) reported on correlations between the type of mobility device use, that is externally modified vehicles and powered wheelchairs (power or manual with power assist wheels), and social participation, based on data collected in the National Spinal Cord Injury Database (NSCID). Data examined from 2986 entries suggest that correlations exist between social participation and using a modified vehicle but between social participation and a wheelchair. The authors suggest their results differ from other studies due to limiting their data to those entries where the person used a wheelchair for more than 40 hours per week and are unable to ambulate more than 150 feet at home.

Chaves et al. (2004) surveyed 70 people with spinal cord injury who use wheelchairs to explore factors that affect the perception of participation in activities in home, in community and during transportation related to the wheelchair, their impairment and the environment. Their primary finding was that the wheelchair was the primary reason cited as a limitation in participation in home, in the community and during transportation with physical impairment being the second reason most often cited and the wheelchair seating being the third. The top four factors that limited access to participation in the community and transportation use were the wheelchair, the physical environment, lack of assistance and wheelchair seating. The authors surveyed people from two centres in different cities, finding significant differences in the characteristics of the participants and in the perception of participation limitations between the cities/centres.

Hatchett et al. (2009) examined shoulder muscle strength and manual wheelchair usage differences based on gender for people with paraplegic level SCI, indicating that the prevalence of SCI for women is increasing and that women have unique attributes that affect these parameters. The strength of all shoulder muscles examined was found to be significantly different between men and women with women's strength being less than men's. Hatchett et al. indicated that shoulder torque, after being normalized for body weight, was the strongest predictor of average daily distance travelled in the community, which for women was almost half of the average distance men propelled daily. However, there was no significant difference in average velocity of propulsion between women and men. The authors identify one of the study limitations being the gender disparity in that 60 participants were male and only seven were females; however, they felt it is enough for a preliminary analysis to support further research into gender differences.

Conclusion

There is level 5 evidence (from one observational study; Hatchett et al. 2009) that suggests that shoulder strength is a strong predictor for average daily distance propelled, and that there are differences in shoulder strength with women's strength being lower than men.

There is level 4 evidence (from one pre-post study; Karmarker et al. 2011 and two observational studies; Phang et al. 2012 and Tolerico et al. 2007) to suggest that 1) wheelchair use varies, particularly propulsion distances, 2) propulsion distance are environmentally dependent and 3) distances decrease with increasing age.

There is level 5 evidence (from two observational studies; Cooper et al. 2011 and Oyster et al. 2011) to suggest that of the cumulative time spent in a wheelchair over the course of a day, a small proportion is spent propelling distances, typically just over an hour a day.

There is level 4 evidence (from one case series study; Tsai et al. 2014) to suggest that the type of wheelchair used is not correlated with social participation.

Wheelchair use varies between individuals, however daily propulsion distance is small amongst most users. Shoulder strength, the user's environment, and age all contribute to propulsion distance amongst wheelchair users, these factors should be considered when developing rehabilitation plans for these individuals.

3.4.2 Falls, Accidents, Repair and Maintenance Issues with Adverse Effects Related to Wheelchair Use

Wheelchair use can be limited by falls and accidents resulting in injury and/or by repairs and maintenance issues. All these factors have potential to affect wheelchair use, to decrease confidence in the equipment or user's skill in operation, impact functional and social activities and, place the person at risk of injury. Falls risk is an important factor to assess for people who use wheeled mobility devices.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Worobey et al. 2012 USA Cohort N=726	Population: Mean age: 42.9 yr; Gender: males=576, females=150; Level of injury: paraplegia=353, tetraplegia=373; Mean time since injury: 12.5 yr. Intervention: Two groups of participants completed surveys at	1. Compared to the historical group (2004-2006), the current group (2006-2011) showed a significant increase in the number of repairs (7.8%) and adverse consequences (23.5%) (p<0.001 for both).

Table 13. Falls, Accidents, Repair and Maintenance Issues with Adverse Effects Related to Wheelchair Use

	different time points (2004-2006 and 2006-2001). Outcome Measures: Demographic data; wheelchair characteristics and occupational status; Type of wheelchair repair and/or breakdown in past 6 mo and; Consequences of breakdown including 1) no consequence, 2) been stranded, 3) been injured, 4) missed work or school, 5) missed a medical appointment.	2. 3. 4.	Compared to manual wheelchair users, power wheelchair users experienced consequences, being stranded, and missing a medical appointment (p<0.001 for all). 64.6% of reported consequences were with power wheelchairs. For wheelchairs with seat functions (tilt, recline, elevating seat/leg rests) there was not a significant number of repairs reported (p=0.156).
		6.	For wheelchairs with seat functions reported more and higher number of adverse consequences (p=0.011 and 0.008 respectively) including greater number of reports of being stranded (p=0.46), of being injured (p=0.004) and missing medical appointments (p=0.024). No significant differences in number of repairs or adverse consequences based on age, years since injury, gender, occupational status or level of education.
Nelson et al. 2010 USA Cohort N=659	Population: Mean age: 55 yr; Gender: males=632, females=27; Level of Injury: cervical=277, thoracic=337, lumbar=45; Severity of Injury: complete=283, incomplete=376; Mean time since injury: 21 yr. Intervention: Questionnaire Outcome Measure: Number of falls and fall related injuries, Comparisons between baseline characteristics and no fall, fall, and injurious fall groups, Comparison of above fall categories with all variables to determine predictors.	1. 2. 3. 4. 5. 6.	Average of w/c use per day=10.9 \pm 4.3 hr 31% of the 659 participants reported 553 fall events; 14% of these sustained an injury; 1 reported death related to fall. Of the 204 participants who reported a fall, 109 (53%) reported more than 1 fall (range 2-53). Of the 208 reported injuries, 179 (85%) were minor, 29 (14%) were serious Predictors of wheelchair related falls included: increased pain in previous 2 mo (p<0.001); positive for alcohol abuse (p=0.01); high FIM score for motor function (p<0.001); history of fall in past year (p<0.001); fewer years with SCI (p=0.007); a shorter length of w/c (p=0.005). Predictors of falls with injuries were; increased pain in previous 2 mo (p<0.001); high FIM score for motor function (p=0.1); history of fall in previous 2 mo (p<0.001); high FIM score for motor function (p=0.1); history of fall in previous year (p<0.001) and lack of accessibility of home entrance (p=0.01).

McClure 2009 USA Case Series N=2213	Population: Mean age: 42.4 yr; Gender: males=1758, females=455; Level of injury: tetraplegia=1121, paraplegia=1061, Mean time since injury: 12.2 yr. Intervention: As part of a larger database data collection survey about assistive technology, the questions specific to wheelchair breakdown and adverse events for people with SCI who use a wheelchair for more than 40 hr/wk were analyzed. Outcome Measures: Frequency of a repair occurrence in the past 6 mo, Frequency of breakdown in the past 6 mo, Consequences of breakdown – participants could choose all that applied:1) No consequences, 2) Being stranded, 3) Being injured, 4) Missed work or school, 5) Missed a medical appointment.	 1. 2. 3. 4. 5. 6. 7. 	971 (44.8%) participants reported at least 1 wheelchair repair within a 6 mo period. Out of 2101 participants that had remembered the number of repairs, 427 (20.3%) had 1 repair, 348 (16.6%) had 2-3 repairs, and 130 (6.2%) completed ≥ 4 repairs. Participants that reported ≥ 1 repair (n=192, 19.7%) reported 262 adverse events; stranded (n=140), being injured (n=42), missing work/school (n=33), or missing a medical appointment (n=47). 8.7% of 2213 participants reported ≥ 1 adverse event. Participants with power wheelchairs had significantly more repairs than participants with manual wheelchairs (power=1.39±3.675, manual=0.81±1.820, p<0.001). Participants with power wheelchairs reported significantly more adverse events compared to participants with manual wheelchairs (106/192, p<0.001) and also experienced more adverse consequences (p<0.001). There were no significant differences in reported repairs between participants with power wheelchairs with power wheelchairs with power wheelchairs with power wheelchairs with power wheelchairs is ported repairs between participants with power wheelchairs with power
			associated with power seat
			functions ($p=0.208$).

Summarized Level 5 Evidence Studies:

The following level 5 evidence studies have been reviewed, and the overarching findings from the studies are highlighted in this section. As noted at the start of this chapter, these types of studies are not included in the discussion or in the conclusions.

In the following observational studies, the authors surveyed large numbers of people related to falls, fall-related injuries and need for wheelchair repairs to explore the frequency and severity of these incidences. Saunders and Krause, (2015) surveyed 759 people with traumatic SCI asking them to recall the incidence of falls and/or injuries they incurred over the previous year related to wheelchair use. Almost 20% reported a fall with 10.4% reporting a resultant injury and 22.8% having at least one hospitalization due to a fall or injury sustained. Similarly, Chen et al. (2011) asked participants to recall accidents in the previous three years (response rate was 79.2%) during telephone interviews. A lack of regular maintenance and the w/c not being professionally

prescribed were found to be associated with increased risk of wheelchair accidents. A lack of regular maintenance and not using seat belts were significant predictors of the cumulative number of accidents. In a secondary analysis, Hogaboom et al. (2018) explored the data from 610 participants with SCI. They found that wheelchair breakdowns that resulted in an immediate consequence such as being stranded, injured, or missing work or an appointment, were associated with reported worse pain and lower self-perceived health. Worobey et al. (2014) retrospectively asked 945 people who used power wheelchairs the frequency of repairs in the previous 6 months. More than 25% of participants reported experiencing at least one repair in the previous six months. Toro et al. (2016) also surveyed people with spinal cord injury to explore the frequency of repairs and resultant adverse outcomes as well as the types of repairs needed, if they were completed and by whom (n=591). 63.8% of respondents reported needing one repair in the past 6 months, (mean =1.5 =/- 2.1), and 27.6% needed more than 1 repair; 21% of participants reported repair for manual wheelchairs and to the electronics and power systems systems for power wheelchairs.

In their 2017 study, Butler Forslund et al interviewed and monitored via text messaging, 149 people with an SCI who reported a total 448 falls in a two-week period. Of this number of falls, 70 resulted in an injury of some type; 67% were minor injury (bruises, scratches, etc.), 23% were moderate injuries (strains and sprains) and 10% were severe (fractures of concussion). The most frequent situations where falls occurred were wheelchair transfers and pushing the wheelchair (18 falls on flat ground, 37 on uneven surfaces and 24 going over gutters or curbs). These authors suggest asking about wheelchar related falls, especially recurrent falls, is critical to identify increased risk for falls. The authors suggest that since most falls are related to pushing the wheelchair, that wheelchair skills training play a key role in falls prevention during intital rehabilitation and when there are changes in functional status.

Based on the large number of participants in all of these studies, and the consistency of high falls frequencies with varying degrees of health outocmes, it is suggested that falls risk identification is an important component of a full wheelchair and seating assessment. Additionally, the impact of wheelchair skills training on falls prevention needs to be researched to determine its viability as a means for reducing falls risk.

Discussion

Nelson et al. (2010) completed monthly monitoring with participants over a one year period to collect data related to wheelchair related falls and injuries for the purpose of identifying 1) the incidence of falls and related injuries, 2) the epidemiology of wheelchair related falls, 3) the severity of injury and 4) identifying associated risk factors that best predict wheelchair related falls and related injuries. The variables collected were compared and contrasted to the groups of no fall, fall and injurious fall to address these purposes. 82% of variances for wheelchair related falls were explained by the predictive factors of: increased pain in previous 2 months, positive for alcohol abuse, high FIM score for motor function; history of fall in past year; fewer years with SCI and; a shorter length of w/c (distance measured between front caster and centre of rear axle). 81% of the variance in wheelchair related falls with injuries was explained by four variables: increased pain in past two months, higher FIM score on motor subscales, history of falls in past year, and lack of accessibility at home entrance. Incidence rates found in this study, 31% reported falls with 14% reporting injurious falls, is reported by the authors to be slightly higher than the national (USA) estimate. The authors suggest that most of the predictive risk factors are modifiable, particularly the shorter wheelchair frame and the lack of accessibility to the home entrance. Therefore, they suggest that recommendations for preventing falls should be incorporated into rehabilitation and as part of all new wheelchair fittings.

Worobey et al. (2012) surveyed 723 participants who used their wheelchair for more than 40 hours per week, to report the incidence of wheelchair repairs, breakdowns and the resultant consequences over a six-month time period. Overall, 52.6% of participants experienced at least one wheelchair repair in the past 6 months with 32.2% experiencing at least one consequence because of the repair/breakdown. Unfortunately, the authors did not differentiate in the data between repair and breakdown, which potentially could hold different meaning and affects for the participants. 31% of participants reported experiencing the consequence of missing work or school and 32% of participants reported and injury. In this study, participants who used power wheelchairs reported more repairs and adverse consequences compared to reports for manual wheelchair use. Of all consequences reported, 65% were accounted for by participants who used power wheelchairs. Wheelchairs with power seat functions also reported significantly higher consequences of being stranded, being injured and missing appointments. The authors also compared results of this study (2006-2011) to historical results (2004-2006), finding that there has been an increase in the incidence of repairs/breakdowns and resultant consequences. The authors suggest that the increasing incidence may be related to a decrease in wheelchair quality due to a lack of standards enforcement and the funding structure in the author's country, for which further investigation is required. It is guestioned whether the separation of repairs versus breakdowns and if regular maintenance was completed would provide additional valuable data for this issue.

Conclusion

There is level 4 evidence (from one cohort study; Neslon et al. 2010) which suggests that tipping or falling from the wheelchair is the most frequently experienced wheelchair-use related accident.

There is level 4 evidence (from one cohort study; Nelson et al. (2010)) to suggest that there are a variety of predictive factors for wheelchair related falls and injuries including a recent increase in pain, recent history of falls, not using seat belts, lack of regular maintenance, the w/c not being professionally prescribed, high FIM scores on the motor subscale combined with a shorter w/c frame length and a lack of accessibility at home entrance.

There is level 3 evidence (from one cohort study; Worobey et al. 2012, one case series study; McClure et al. 2009) to suggest that in a six month time period between one quarter and one half of wheelchairs will require a repair and that of these repairs up to one third will result in an adverse effect.

Many of the predictive risk factors for wheelchair related falls and resultant injuries are modifiable; therefore, considerations and education related to preventing falls should be included in wheelchair interventions.

Maintenance and repair issues arise frequently for people who use wheelchairs therefore are important considerations in the wheelchair service delivery process and the manufacturing process.

3.4.3 Wheelchair Satisfaction

In the literature, satisfaction with wheelchair use is reflected in satisfaction with wheelchairrelated components and with performance as well as with the aspects of service delivery such as the provision process, repairs, and professional services. The highest level of evidence of the studies in this section is level 5, therefore the standard method of presentation using table, discussion and conclusions is used.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Amosun et al. 2016 South Africa Observational N=75	 Population: Age range: 16-65 yr; Gender: N/R; Level of injury: N/R; Mean time since injury: 9.3 yr. Intervention: Pariticpants filled out a four- part questionnaire to asses the extent to which wheelchairs met the activity and participation needs of users, as well as the users' level of satisfaction with the provision, repair and maintenance of these wheelchairs. Outcome Measures: Four-part questionnaire: Demographic and background information; Functioning Everyday in a Wheelchair (FEW) instrument; Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0) instrument; 6 questions by Samuelsson and Wressle. 	 Participants had used wheelchairs for an average period of 9.3 years. Most participants (61%) had sustained spinal cord injuries, and used three-wheeler chairs (76%). > 90% reported that their wheelchairs positively influenced their activity and participation needs, and 85% were satisfied with their ability to carry out daily activities. Participants expressed satisfaction with the durability of the wheelchairs (89%), and the professional services received (71%), but not with follow-up services (77%). There was difference in satisfaction with features of 3-wheeler and 4- wheeler rigid chairs (p=0.030).
Gil-Agudo et al. 2013 UK Observational N=6	Population: Mean age: 32 yr; Gender: males=6, females=0; Level of injury: T1=1, T3=2, T8=1, T11=2; Mean time since injury: 62 mo. Intervention: Participants used three different wheelchairs (Kuschall Champion®, Otto bock Voyager®, and Invacare Action®) to complete evaluation circuits consisting of: 1) Activities of Daily Living driving course including corridor, ramp, curb, tile surface, sand surface, bumps, potholes , turning, figure- 8 and 360° wheelie, 2) activities including making a bed, toilet and car transfers which included lifting the w/c into the car and 3) sprint distance of 25 m. Outcome Measures: 1) 5 point rating scale for w/c manoeuverability, stability, comfort, ease of propulsion2) 10 point Visual Analogical Scale (VAS) rating perceived level of satisfaction.; 3) Kinetic data using a SMART wheel to measure average total push force, average speed, average contact angle, average cadence.	 Compared to the Invacare wheelchair, the Kuschall and Otto Bock wheelchairs had significantly better manoeuvrability scores (p=0.05 for both) and VAS scores (p<0.05 for both). Cadence was the only noted kinetic difference with the Kuschall cadence being greater than all other w/c's tested (p<0.05) Significant differences were noted between the various chairs for toilet transfers, 360° wheelie rotation, bed transfer, and car transfer. No differences were noted in physiological variables between wheelchairs

Table 14. Wheelchair Satisfaction

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
de Groot et al. 2011 Netherlands Observational N=109	Population: Mean age: 40.4 yr; Gender: males=80, females=29; Level of injury: tetraplegia=30, paraplegia=79; Level of severity: complete=78, incomplete=31; Mean time since injury: 708 days. Intervention: Participants were administered the Dutch version of the Quebec User Evaluation of Satisfaction with Assistive Technology (D-QUEST). Outcome Measures: Satisfaction with assistive technology.	 No differences in the subscale scores were found between age groups, gender, lesion level and those with a high or low UAL score (p<0.05 for all). Participants with an incomplete lesion, lower SIPSOC score, and/or were more active had higher satisfaction with service-related aspects (p=0.05, p<0.001, and p=0.03, respectively) Compared to participants with a complete lesion, participants with an incomplete lesion were more satisfied regarding wheelchair-related aspects (p=0.02).
Rushton et al. 2010 Canada Observational N=51	Population: Mean age:43.7 yr; Gender: males=43, females=8; Level of injury: tetraplegia=33, paraplegia=18; Level of severity: complete=18, incomplete=33; Mean time since injury: 16.1 yr. Intervention: Participants completed a questionnaire. Outcome Measures: Wheelchair outcome Measure (WhOM), Quebec User Evaluation of Satisfaction with assistive Technology (QUEST).	 There were 258 indoor and 257 outdoor participation outcomes identified by this sample with most outcomes falling into the "community, social, and civil life" (36.5%), "domestic life" (23.7%), and "mobility" (18%) domains. All domains had a mean satisfaction score of 7.1/10 or greater except for the indoor "mobility" domain which had a mean satisfaction score of 6.1/10.
Chan & Chan 2007 China Observational N=31	Population: Mean age: 41.7 yr; Gender: male=25, females=6; Level of injury: C1- C4=9, C5-C8=8, T1-T9=8, T10-S=6; Severity of injury: AIS A=22, B=3, C=1, D=5; Mean time SINCE injury=3.8 yr. Intervention: Participants completed a set of questionnaires. Outcome Measures: Chinese version of the Quebec User Evaluation of Satisfaction with Assistive Technology (C-QUEST), World Health Organization Quality of Life Questionnaire (WHO QoL-BREF (HK)), "Participation Restriction" and "Environmental Factors" of the International Classification of Functioning Disability and Health (ICF).	 Transportation and driving were moderately and highly correlated, respectively, with QoL. Participation in societal functions, such as traveling in the community and participating in leisure activities were related to higher QoL. A moderate association between perception of interpersonal relationships and QoL in the paraplegia population. Wheelchair satisfaction was better associated with QoL than with perception of community participation and environmental factors. Mild association between the C- QUEST Services scores and the ICF sub score of Health-related Professionals.
Fitzgerald et al. 2005 USA Observational N=110	Population: Mean age: 49.2 yr; Gender: male=94, females=16; Injury etiology: SCI=75, MS=9, Cp=6, amputation=7, muscular dystrophy=2%, spina bifida=2%, TBI=1, post-polio=1, Other=7; Mean time since injury=19.6 yr. Intervention: Participants completed a questionnaire about their wheelchairs, number of repairs and satisfaction in 10	 26% of the participants had wheelchair repairs in the prior 6 month;43% reported regular maintenance (manual wheelchairs were more likely to be regularly maintained than power) Power wheelchairs required significantly more repairs than manual wheelchairs (p<0.001).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	areas (durabiiy, use, simplity of use, overall appearance, dimensions, delivery, transportation, overall fit, and owner's manual). Outcome Measures: Visual analog scale for satisfaction, Number and type of wheelchair repairs.	 Participants using manual wheelchairs were significantly more satisfied (p<0.05) according to the VAS in 7 of 10 satisfaction categories. Participants who had performed no repairs were significantly more satisfied than participants performing one or more repairs.

Fitzgerald et al. (2005) explored the relationship between wheelchair satisfaction and wheelchair durability which they defined as requiring repairs and maintenance for both manual and power wheelchairs in the previous six months. Study findings indicated that participants were generally satisfied with their wheelchair, with scores ranging from 7.0 to 8.2. Interestingly the researchers reported that highest scores were in wheelchair appearance and simplicity of use and the lowest were in comfort and service delivery. People who used manual wheelchairs were significantly more satisfied with their wheelchair than people who used powered in all categories except in appearance, delivery and owner's manual. The satisfaction with wheelchair durability was high on the VAS despite that 26% of participants reported needing repairs in the past six months.

De Groot et al. (2011) described the satisfaction expressed by people with spinal cord injury who use manual wheelchairs, in relation to aspects of the manual wheelchair and service delivery as well as the relationship between satisfaction with wheelchair use and participation. Simlar to Fitzgerald et al. (2005), a high level of satisfaction was found with regards to simplicity of use, effectiveness, safety and dimensions of the wheelchair but lower scores for comfort. The authors also found a higher wheelchair-related satisfaction associated with a more active lifestyle as per the PISIPD score albeit not a strong association. The authors suggest the link between wheelchair satisfaction and active lifestyle highlights the importance of a good wheelchair fit as noted in other studies. Satisfaction. Slowness of the process was a primary reason for dissatisfaction. Approximately 60% of participants indicating satisfaction with repairs/servicing, professional services and follow up services indicating moderate satisfaction with service delivery.

Rushton et al. (2012) explored satisfaction through linking the self-identified participation outcomes of 51 people with spinal cord injury with the domains of the International Classification of Functioning Disability and Health (ICF) The Wheelchair Outcome Measure (WhOM) was used to guide and develop the wheelchair use related participation outcomes as well as to rank level of satisfaction of these self-identified outcomes. The outcomes linked to at least the third level of ICF sub-domains; the authors noted that the outcomes did not link well to other ICF domains. The authors discuss that the high frequency of and satisfaction with indoor and outdoor outcomes in the "community, social and civil" domain is consistent with other research studies. The authors suggested that daily life participation outcomes for which a wheelchair is required as well as those for which a wheelchair is not required, may provide a more comprehensive understanding of how wheelchairs are integrated within daily life.

Chan and Chan. (2007) explored the relationships between wheelchair users' satisfaction, perceptions of participation, environmental influence and quality of life (QoL) via telephone survey. The results presented here focus only on the findings related to wheelchair use satisfaction. The authors suggest that the more supportive the relationship with the health-related professional the more satisfied the participant was with wheelchair use. The authors also suggest that the findings indicate satisfaction with wheelchair use was more associated with QoL than with participation and environmental influences, however some particular areas of community participation and environmental factors were associated with QoL such as travelling in the community, using public transport or driving, and engaging in leisure activities.

Gil-Agudo et al. (2013) chose to examine the satisfaction and effectiveness of wheelchair use based on product-centred evaluation approach including functional performance information, physiologic and kinetic information as well as perceptions of fit and performance from the person using the wheelchair. Given the study sample size was six participants, interpretation of the results related to the identifying the best performing wheelchair product is limited. As wheelchair selection should be individualized, the process of reviewing performance and satisfaction outlined in this study may prove to be of assistance in individualizing wheelchair selection process as it provides a more structured means of individual wheelchair evaluation to ultimately improve wheelchair use satisfaction.

Similar to the other studies, Amosun et al. (2016) used the Quest 2.0 in the developing country of Tanzania to explore wheelchair satisfaction. Their findings were similar to the above studies inthat respondents indicted satisfaction with wheelchair-related aspects such effectiveness of use, and enabling participation in activities, however a smaller number of respondents expressed satisfaction with service-related aspects. Authors also found a large proportion of respondents expressed dissatisfaction with transportation.

Conclusion

There is level 5 evidence (from five observational studies; Amosun et al. 2016; de Groot et al 2011; Rushton et al. 2012; Fitzgerald et al. 2005; Chan & Chan, 2007) that satisfaction with wheelchair use is moderate to high for people with spinal cord injury who use wheelchairs.

There is level 5 evidence (from two observational studies; de Groot et al 2011, Fitzgerald et al. 2005) that satisfaction with wheelchair-related service delivery is lower than satisfaction with wheelchair use, primarily due to the slowness of the process, and less so with regards to repairs/service, professional services and follow up services.

There is level 5 evidence (from two observational studies, Rushton et al. 2012; Chan & Chan, 2007) suggesting that wheelchair satisfaction is more highly focused on quality of life variables such as participation in leisure activities.

Optimizing the potential for satisfaction with wheelchair use requires consideration of the fit and function of the wheelchair during the service delivery process particularly for quality of life-based activities such as leisure pursuits; satisfaction with the service delivery process requires timeliness throughout the wheelchair provision process.

3.4.4 Wheelchair Skills

Wheelchair skills represent the specific abilities that wheelchair users need to get around their environments and use their wheelchairs in daily activities. The Wheelchair Skills Training Program (WSTP) (https://wheelchairskillsprogram.ca/en/) is the best known and most tested wheelchair skills training intervention. It is a freely available skills training program for caregivers and users of manual wheelchairs, power wheelchairs and scooters. There are two main measures of wheelchair skills used in the SCI literature reviewed, 1) the Wheelchair Circuit and 2) the Wheelchair Skills Test (WST) (it is the outcome measure used as part of the WSTP). The Wheelchair Circuit Examples includes eight to nine tasks: figure-of-eight shape, doorstep crossing, mounting a platform, 15 m sprint, 15 m walk (for those who ambulate), driving on a treadmill up slopes of 3% and 6%, wheelchair driving (on treadmill five minutes at a speed of 0.83 m/s), and transfer. Sub-scale scores for ability (ordinal scale); performance time (seconds); and physical strain (using HR data) are calculated. The Wheelchair Skills Test is an evolving measure. There is an objective version in which a rater documents a wheelchair user's capacity to perform indoor, community and advanced wheelchair skills. Indoor wheelchair skills include the ability propel the wheelchair forwards and backwards on level surfaces, turn the chair, get in and out of the chair, negotiate doors, get objects from the floor and upward reaching. Examples, of community skills include folding and unfolding the wheelchair, and negotiating curbs, shallow ramps and cross slopes. Advanced skills include negotiating steeper slopes and performing wheelie related skills. There is also a self-report version of the measure called the Wheelchair Skill Test Questionnaire (WST-Q). Among people with SCI, the best predictors of wheelchair skills on discharge from in patient rehabilitation (measured using the the Wheelchair Circuit) are performance time and ability score at baseline, age, sex and lesion level (de Groot et al., 2010). A study from eight rehabilitation centres in the Netherlands found that wheelchair skills performance, measured using the Wheelchair Circuit was negatively associated with age and lesion level and positively associated with self-efficacy perceptions (Fliess-Douer et al 2013). The study also found that wheelchair skills performance remained stable during the first year after discharge from rehabilitation. Among people with SCI, return to work five years post injury has been associated with higher wheelchair ability scores, and lower performance time and physical strain as measured using the Wheelchair Circuit (van Velzen et al., 2012).

Author Year Country Research Design Score Total Sample Size	Methods		Outcome
	Outcomes of Wheelchair Skills	Trair	ning
Yeo et al. 2018 Korea RCT PEDro=4 N=24	Population: <i>WSTP Group</i> (<i>n</i> =13): Mean age= 35.3 yr; Gender: males=10, females=3; Level of injury: C5-T1; Mean time since injury: 2.9 yr. <i>CG</i> (<i>n</i> =11): Mean age= 35.9 yr; Gender: males=9, females=2; Level of injury: C5-T1; Mean time since injury: 2.9 yr. Intervention: Manual wheelchair users were randomized to either the WSTP (consisting of hands-on demonstrations and practice of wheelchair skills), or the control group (CG) consisting of conventional exercise sessions. Interventions occurred 3x/wk for 8wks.	1.	Compared with the CG, the WSTP group improved in WST score at 4 and 8 wks. Compared with the CG, the WSTP improved on the VLT-SV at 8 wks.

Table 15. Wheelchair Skills

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Outcome Measures: Wheelchair Skills Test Questionnaire (WST-Q), <u>Van Lieshout</u> <u>Test short version (VLT-SV)</u> (measures arm and hand function).	
Kirby et al. 2016 Canada RCT PEDro=7 N _{initial} =106 N _{initial} =82	Population: WSTP Group (n=53): Mean age= 48.1 yr; Gender: males=51, females=2; Level of injury range: C-T; Mean time since injury: 16.6 yr. EC Group (n=53): Mean age= 47.1 yr; Gender: males=50, females=3; Level of injury range: C-T; Mean time since injury: 18.2 yr. Intervention: Participants were randomized to either the Wheelchair Skills Training Program (WSTP), or the Educational Control (EC) group. Each participant received 5 one-on-one WSTP or EC sessions for 30-45min. Outcome Measures: Wheelchair Skills Test (WST), Craig Handicap Assessment and Reporting Technique (CHART).	 WST scores improved significantly in the WSTP group compared to EC group from baseline to follow-up (p<0.001). CHART improved significantly for WST group compared to EC group from baseline to follow-up (p=0.21).
Worobey et al. 2016 USA RCT PEDro=7 N _{initial} =114 N _{initial} =79	 Population: WSTP Group (n=36): Mean age= 40.1 yr; Gender: males=32, females=4; Level of injury: N/R; Mean time since injury: N/R. CG (n=43): Mean age= 41.0 yr; Gender: males=37, females=6; Level of injury: N/R; Mean time since injury: N/R. Intervention: Participants were randomized to either the Wheelchair Skills Training Program (WSTP) consisting of hands-on demonstrations and practice of wheelchair skills, or the control group (CG) consisting of PowerPoint presentation. WSTP group participated in six 90min classes. The CG participated in two 1hr active control sessions. Outcome Measures: Wheelchair Skills Test Questionnaire (WST-Q), Goal Attainment Scale (GAS) 	 Compared with the active control group, the WSTP group improved in WST-Q capacity advanced score (p=0.02), but not in WST-Q capacity or WST-Q performance total scores (p=0.068, p=0.873, respectively). GAS score did not significantly differ between groups, however those who attended a greater number of classes had a higher GAS score (R=0.531, p=0.001).
Routhier et al. 2012 Canada RCT PEDro=7 N=39	Population: Wheelchair Skills Training Program (WSTP) group: Mean age: 48.9 yr, Gender: males=13, females=6; Mean height: 164.5 cm; Mean weight: 83.7 kg. Control group: Mean age: 43.1 yr, Gender: males=13, females=6; Mean height: 163.5 cm; Mean weight: 70.2 kg. Intervention: Participants were randomly put into either the control group or WSTP group. Both groups were given standard care but the WSTP group was also given a mean of 5.9 training sessions with standard care. Outcome measures: Wheelchair Skills testing.	 Total P(WSTP versus control at t2): p=0.030. P(t2 versust3): WSTP p=0.990, Control p=0.641. WSTP training shows improvement in wheelchair skill right after the training particularly in community skills level but the Statistical significance was not reached between groups at 3 mo follow- up.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Ozturk & Dokuztug 2011 Turkey RCT PEDro=5 N=24	Population: Training Group (n=14): Mean age: 38.8 yr; Gender: males=5, females=9. Control Group (n=10): Mean age: 28.7 yr; Gender: males=6, females=4. Injury etiology: SCI=13, Other=11. Intervention: Participants, who were manual wheelchair users (rear-wheel drive), were randomly assigned to either the training or control (no training) group. The training group received the Wheelchair Skills Program (45 min, 3x/wk for 4 wk). Supervised by a physiotherapist, sessions targeted basic skills and progressed to more advanced wheelchair skills. Session content was developed after a trainer observed the individual in their living environment. Outcome Measures: Wheelchair Skills Test (WST).	 The mean time between baseline and follow-up was 35.5±6.4 days in the training group and 30.8±3.6 days in the control group (p=0.013). Within-group analysis showed a significant increase in WST performance scores for both the training (p=0.002) and control groups (p=0.01); however, statistically significant improvements for WST Safety scores were only found in the training group (p=0.001). Comparing between groups, when controlling for baseline WST values, the performance and safety scores remained significantly higher in the training group (p=0.001 and p<0.001, respectively).
	Evaluation of wheelchair skills trainin	g approaches
Lalumiere et al. 2018 Canada RCT Crossover PEDro=4 N=18	Population: Mean age= 39.3 yr; Gender: males=17, females=1; Level of injury range: N/R; Mean time since injury= 11.7 yr. Intervention: Manual wheelchair (MWC) users performed wheelies on four different rolling resistances: natural hard floor (NAT), 5-cm thick soft foam (LOW), 5-cm thick memory foam (MOD), rear wheels blocked by wooden blocks (HIGH). The order of the tests was random. Measurements were taken pre and post intervention. Outcome Measures: Center of pressure (CoP), center of pressure mean distance (MDIST), center of pressure mean velocity (MVELO), elliptical area (AREA-CE), mean power frequency (FREQ-50%), centroidal frequency (CFREQ), frequency dispersion (FREQ-D).	 The MDIST measure values significantly increased (p≤0.001) between the NAT versus LOW and MED versus HIGH conditions. The MVELO values significantly increased (p≤0.008) between the NAT versus LOW, LOW versus MOD, and MOD versus HIGH conditions. The AREA-CE significantly decreased (p≤0.002) between the NAT versus LOW and MED versus HIGH conditions. FREQ-50%, CFREQ and FREQ-D all significantly increased (p≤0.002, respectively) in NAT versus LOW and MOD versus HIGH conditions.
Wang et al. 2015 USA RCT PEDro=5 N=21	 Population: Experimental Group (n=9): Mean age: 33.2 yr; Gender: males=6, females=3; Level of Injury: T1-L1=9. Controls (n=9): Mean age: 34.5 yr; Gender: males=6, females=3; Level of Injury: T2- 12=9. Intervention: Patients were randomly allocated to an experimental group with immediate video feedback during wheelchair training or a control group with conventional training. Three skills were taught: ramp wheelie and curb. The experimental group observed a video of a model performing the target skill and then attempted to perform the skill whilst being filmed. Patients then reviewed the model 	 There were no significant differences between groups concerning training time required to complete each skill and in the number of spotter assistance for all three tasks, however, the experimental group required significantly less spotter assistance during the curb skill training (p<0.05). No significant differences were found between groups regarding completion time of the curb skill and the ramp skill during all three tests but the experimental group completed the wheelie skill significantly quicker than the control group during the competency test (p<0.05). There were no significant

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	video and their own performance to identify differences in performance. All training sessions were conducted 2/wk until the patient had mastered the target skill they had been working on. A skill competency test was administered after 3-4 wks of training followed by a retention test 1 wk after passing the competency test. A transfer test (doing the skill in a different environment) was completed 1d after passing the retention test. Outcome Measures: Time spent completing wheelchair skills during training and testing, Number of occurrences requiring spotter assistance, Success rates during testing.	 differences in completion time for the wheelie skill during the retention and transfer tests. 3. The experimental group required more spotter assistance for the curb skill and yielded a significantly lower success rate than the controls (both p<0.05) during the transfer test.

Five intervention studies explored outcomes associated with wheelchair skils training. Ozturk et al. (2011) found a four-week skills training program for community dwelling manual wheelchair users in Turkey resulted in significant improvements in performance and safety immediately after training (measured using the Wheelchair Skills Test); however, longer term changes were not measured. Yao et al. (2018) all found that after eight weeks participants who received wheelchair skills training had significantly better wheelchairs skills and upper extremity motor skill performance cmparted to people who received education. Worobey et al. (2016) found that after 4-6 weeks of intervention, only participants' advanced wheelchair skills improved compared to those who received education. Routhier et al. (2012), examined the effect of skills training on wheelchair skills, measured using the Wheelchair Skills Test. This study found a significant improvement in skills immediately after training, but that the difference was not significant at three months follow up. In contrast, Kirby et al. 2016, found that significant improvements in Wheelchair Skills Test scores after five training sessions that was maintained 12 months after the intervention. Improvements in mobility participation were also noted. In summary, several studies have demonstrated that wheelchair skills training among people with spinal cord injury can result in immediate improvements in skills; however, there is less certaintly about maintenance of these improvements over time. There is limited research about other outcomes including safety, mobility and social participation.

Two studies evaluated wheelchair skills training approaches. A study by Lalumier et al. 2018, explored different strategies for training wheelchair users to perform wheelies. Although it did not develop a specific protocol, it recommends blocking the rear wheels initially and then rapidly progressing to foam or natural suraces to improve postural control strategies and refine skills. Wang et al. 2015 compared conventional skills training and a video feedback intervention, in which the experimental group observed a video of a model performing the target skill and then attempted to perform the skill while being filmed. Patients then reviewed the model video and their own performance to identify differences in performance). The interventions were generally quite similar, although the experimental group needed less spotter interventions during the initial testing and required more during transfer testing and had a lower success rate (i.e., it may be

less effective when getting participants to transfer curb climbing they have learned in one setting to a different setting).

Conclusion

There is level 1b evidence (from five RCT studies; Kirby et al., 2016; Ozturk et al. 2011; Routhier et al. 2012; Worobey et al., 2016; Yeo et al., 2018) that manual wheelchair skills training causes an immediate improvement in wheelchair skills.

There is level 2 evidence (from one RCT study; Wang et al. 2015) that video feedback during training produced similar results as conventional training.

There is mixed evidence regarding how well skills learned are retained (Routhier et al. 2012; Kirby et al., 2018).

There is level 1 evidence that when learning to perform wheelies improvements in postural stability are noted when the rolling resistance is increased (Lalumiere et al., 2018).

There is good evidence that wheelchair skill training can improve skills in the short term and that video feedback produces similar results as conventional skill training.

There is strong evidence that manual wheelchair skills training causes an immediate improvement in wheelchair skills, but is mixed evidence regarding how well skills learned are retained

When learning to perform wheelies improvements in postural stability are noted when the rolling resistance is increased.

The focus of wheelchair skills training during shortening rehabilitation stays should consider the person's home and community environments and activities is needed as it is suggested that not all skills are essential to functioning in daily life.

4.0 Power Wheelchairs

Power wheelchairs are frequently prescribed to provide or enhance independent mobility, thereby facilitating increased participation in daily life. Mobility and independence have been linked to improved overall quality of life especially for people with spinal cord injury (Sonenblum et al. 2008). Compared to manual wheelchairs, there is significantly less research that explores power wheelchair use for people with spinal cord injury despite the important role power wheelchairs play in a person's daily life and health. This research in this area has been organized into the subsections of: characteristics of power wheelchair use, power wheelchair driving controls, and power positioning device use. This latter section foucses on how this technology is used in daily life; research related to the benefits of using power positioning is presented in section 6.0, Positioning Changes for Managing Sitting Pressure/Postural Issues, Fatigue and Discomfort.

4.1 Characteristics of Power Wheelchair Use

Studying the characteristics of power wheelchair use sheds some light onto how and why people use their power wheelchairs and if the devices are meeting their needs in everyday life. Gaining an understanding of actual power wheelchair use may provide guidance and direction in decision-making for the provision of power wheelchairs.

Author Year Country PEDro Score Research Design Total Sample Size	Methods	Outcome
Daveler et al. 2015 USA Observational Phase 1 N=31 Phase 2 N=N/A Phase 3 N=12	 Phase I Population: Mean age: 55.9 yr, Gender: males=26, females=6; Mean w/c experience:13 yr. Intervention: Survey regarding current wheelchair characteristics and perceived rating of difficult driving scenarios. Outcome Measures: Ratings of 23 driving scenarios by degree of difficult; power wheelchair drive wheel location. Phase III Population: Mean age: 46.9 yr; Gender: males=7, females=5; Mean w/c experience:16.3 yr. Intervention: Questionnaire about outdoor driving places visited in the past week, frequency encountering a terrain/architectural barrier and the action they performed at that time, Outcome Measures: Obstacle frequency, action taken upon obstacle encounter, features most likely to use if avaialble. 	 Phase I The position of the drive wheel (FWD, RWD, and MWD) showed the greatest differences in driving difficulty reported especially in mud, gravel and cross slope conditions. Avoidance of these conditions when encountered was reported: 1) in mud 70% of RWD and MWD, 33% of FWD; 2) in gravel 54% of RWD, 31% of MWD, 17% of FWD and: 3) in cross slope conditions 31% of RWD, 50% of FWD and 62% of MWD. >50% of participants mentioned that the conditions: uneven terrain, driving up and down steep hills, cross slopes, gravel, curb cuts, and ramps where particularly difficult to maneuver. Phase III Top 5 obstacles encountered at 1-3 times/wk: small curb, cross slope, grass, dirt/mud, curbs); >3 times/wk: curb cuts door thresholds concrete, carpet up and down ramps. Top 5 avoided obstacles: sand, curbs, gravel, dirt/mud, small curbs. Top 4 obstacles that required assistance: grass, dirt/mud, door threshold, gravel. Curb climbing and traction control were featuring most likely to be used by study subjects in different terrain.
Hastings et al. 2011 USA Observational N=30	Population: Mean age: 47 yr; Level of injury: SCI, C6-C7, tetraplegia; Mean time since injury: 16 yr; Mean length of rehabilitation: 4.5 mo; Mean BMI: 23.7; W/c use: manual=18, power=12. Intervention: Demographic information and three questionnaires. Outcome Measures: Rosenberg Self- Esteem Scale (RSES), Spinal Cord Independence Measure III (SCIM), Craig Handicap Assessment and Reporting Technique (CHART).	 No significant differences between manual and power group with respect to demographic information. Significant differences found between wheelchair groups in SCIM III (F=11.088, p=0.003) and CHART subscales of Physical (F=7.402, p=0.011), Mobility (F=12.894, p=0.001), and Occupation (F=5.174, p=0.031). No difference between groups for self- esteem (RSES) and CHART cognitive and social subscales.
Sonenblum et al. 2008 USA Observational N=25	Population: Mean age: 43 yr; Gender: males=16, females=9; Injury etiology: SCI; Level of injury: cervical=12, thoracic=1; Level of severity: complete=8, incomplete=4; Median time since injury: 10 yr.	 Most wheelchair use occurred at home; outdoor period of use were longer in time and distance and faster in speed than indoor periods (p<0.001). Median time in wheelchair was 10.6 hr (5.0-16.6 h): distance wheeled ranged

Table 16. Power Wheelchair Characteristics Wheelchair

Author Year Country PEDro Score Research Design	Methods	Outcome	
Total Sample Size	Intervention: Tracked wheelchair mobility use for 13-15 days in-home and community using a data logger; telephone interview. Outcome Measures: Wheelchair usage, location used, distance wheeled, time spent wheeling, time spent in the wheelchair, time in wheelchair spent wheeling.	 0.24-10.9 km (median 1.1 km) over range of 16-173 min (mean 58 min). Mean of 9.2% of time in wheelchair was spent wheeling. Time spent wheeling and number of mobile periods had normal distribution. Occupancy time was most normally distributed and least varied variable. No consistent usage pattern across and within subjects. Day-to-day variability in mobility was igh regardless of how much a subject 	
Hunt et al. 2004 USA Observational N=412	Population: Mean age: 42 yr; Gender: male=325, females=87; Level of injury: paraplegia=210, tetraplegia=202; Mean time since injury: 8.9 yr; Wheelchair: manual=251, power=161. Intervention: In-person or telephone survey on demographic, socioeconomic and assistive technology data. Outcome Measures: Number and type (manual or power) wheelchair, Wheelchair customizability as defined by design features (e.g., axle adjustment, programmable controls).	 97% manual wheelchair users had customizable wheelchair. 46% power wheelchair users had programmable and 54% had customizable wheelchair. 40% of manual wheelchair users had at least one additional wheelchair (73% had additional manual, 27% power) and 57% of power wheelchair users had at least one additional wheelchair (84% manual, 16% power). People with at least one additional wheelchair were more likely to be white (p=0.001), have higher income (p=0.0045). 	
Biering-Sorenson et al. 2004 Denmark Observational N=236	Population: Mean age: 50.5 yr; Gender: males=193, females=43; Level of injury: tetraplegia, paraplegia; Level of severity: complete=102, incomplete=134; Mean time since injury: 24.1 yr. Intervention: Medical chart review, Questionnaire regarding mobility aids. Outcome Measures: Functional classification at time of injury, Rehabilitation discharge functional classification, Mobility aids, transportation at time of follow-up.	 3.4% had no mobility devices; only men used standing frame and stand-up wheelchair (gender difference, p=0.0026). Manual and power wheelchair used by 83.5% and 27% respectively, with power used more by those with tetraplegia (p<0.001). 9.3% had neither manual nor power wheelchair. majority of those who use their walking ability also use a manual wheelchair, power wheelchair or scooter for longer distances 32% with manual wheelchair also had a power wheelchair or scooter. 	
Cooper et al. 2002 USA Observational N=17	Population: Mean age: NR; Gender: males=11, females=7; Injury etiology: SCI=9, MS=1, spina bifida=1, polio=1, head injury=1, muscular dystrophy=1, lower motor neuron disease=1, CP=2; Level of injury: paraplegia=3, tetraplegia=6; Chronicity: chronic; Mean duration w/c use: 14.5 yr. Intervention: Wheelchair use monitoring using a data logger and standardized questions for both	 Wheelchair athletes travelled faster than regular users, but this trend was significant only on day 1. Wheelchair athletes were more likely to travel farther (significant difference day 4 (p=0.03) and day 5 (p=0.05). Total distance travelled over 5 days and average distance travelled per day were significantly different (p=0.02) with the active group travelling further (17164±8708 m versus 8335±7074 m). 	
Author Year Country PEDro Score Research Design Total Sample Size	Methods		Outcome
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	wheelchair athletes (n=10) and regular use individuals (n=7). Outcomes Measures: Speed, Distance travelled, Time wheelchair was being used in 24 hr.	4.	No significant difference between type of wheelchair and distance or speed over the 5 days.

Cooper et al. (2002) examined the driving characteristics of two groups of people; group one was 10 athletes competing in a local wheelchair games, group two were seven people living in the community regularly using their power wheelchair. On average the athletic group travelled farther and faster than the regular use group, which the authors feel can be largely attributed to the amount of available activities, easily available transportation and social context available at the competition. Overall study findings indicated that the speed at which participants drove their wheelchairs most of the time, was much less than the available maximum speed, with full speed driving only for a few meters occasionally. This was the same for distance travelled; there was more battery life available than was used. This study found little variability in driving speed patterns across participants.

Sonenblum et al. (2008) found that bouts of mobility indoors occurred frequently but at slower speeds and shorter distances than bouts used outdoors. A bout was defined as transitional mobility between stationary activities. The average daily distance travelled was 1.9 kilometers; the distance that was travelled varied across participants as well as across days for the same person. The key finding from this study was that there was no typical pattern of power wheelchair use whether across people or across days for the same person.

Hastings et al. (2011) determined if differences existed between those who used power wheelchairs and those who used manual wheelchairs. The data was collected using questionnaires for self-esteem, function and participation. There were significant differences observed between manual and power wheelchair users, however, there were several confounding factors which the authors acknowledged as limitations but did not account for in the results. Of greatest concern is that the study did not account for varying motor function (e.g., complete versus incomplete injury, antigravity versus gravity-eliminated triceps function). The article suggests that people who sustained a C6-7 motor level injury are better able to maintain physical use of muscles above the injury, move around the environment more and attain employment in a manual wheelchair than power. Given these limitations the results should be interpreted carefully.

To understand the characteristics around the type of wheelchair a person uses, Hunt et al. (2004) surveyed 412 people with spinal cord injury who used a wheelchair for more than 40 hours a week. 97% of manual wheelchairs users had an ultralight, customizable wheelchair and 54% of power wheelchair users had programmable controls with customizable features. Findings also indicated that 40% of manual wheelchair users had at least one additional chair with 73% being an additional manual wheelchair and 27% being power. 57% of power wheelchair users had at least one additional chair with 84% being manual and 16% being power.

Biering-Sorensen et al. (2004) examined mobility aids being used at least 10 years post injury based on data gathered from a larger follow up study. The results from this paper highlight the wide variety of mobility devices are used by people with SCI and that many have more than one device. The study did not account for possible influence of neurological or functional recovery on device use between initial injury and this follow up study. It also did not account for possible changes in mobility devices during the time period from initial injury to post injury 10-45 years later.

Daveler et al. (2015) completed a three-phase observational study to understand the conditions and barriers that users of powered wheelchairs find difficult to drive in/over in the outdoor environment. The ultimate goal of this study was to develop a powered mobility device which addressed many of these issues/challenges. This review focused on the results as they relate to how power wheelchairs are used in the environment therefore only the results from phase 1 & 3 are presented as phase 3 was a trial of a prototype device. The findings indicate that people who use power wheelchairs encounter daily environmental challenges to mobility and that the location of the drive wheel affects how the wheelchair responds to that challenge. However, a particular drive wheel location did not stand out as preferable. Given that many of the difficult conditions idenitified by participants are similar to the items used in many of the wheelchair training programs it is questioned if the challenges could be addressed in part or in whole, with in-depth power wheelchair skills training (e.g. ascending/descending curbs and ramps and traversing door thresholds).

Conclusion

There is level 5 evidence (from one observational study; Hunt et al. 2004) that to meet full mobility needs, a wide variety of mobility devices are often used in conjunction with power wheelchairs.

There is level 5 evidence (from two observational studies; Sonenblum et al. 2008; Cooper et al. 2002) that there are no typical patterns of power wheelchair use in daily life but small bouts of movement or short distances at high speeds were more frequent.

There is level 5 evidence (from one observation study; Daveler et al. 2015) to suggest that there are people who drive power wheelchairs experience daily driving challenges such as door thresholds, and frequently encountered driving situations such as uneven terrain, curb cuts, gravel, and mud.

Considerations for how individuals use power wheelchairs should include more than distance and speed travelled, as most people spend little time travelling any distance compared to the amount of time they spend in their power wheelchair. For the SCI population power wheelchair provision needs to include at a minimum customizable programmable control.

Consideration should be given to the potential provision of both power and manual wheelchairs to meet basic living needs for the SCI population.

4.2 Power Wheelchair Driving Controls

Power wheelchairs are controlled by a variety of technologies, from conventional joysticks to head arrays and sip and puff systems. However, little research has been completed on the use or effectiveness of these types of power wheelchair driving controllers, whether conventional or alternative. Several studies have explored novel prototype methods for controlling power wheelchairs, but these studies offer little for clinical application and relevance at this time so have not been included in this chapter.

4.3 Power Positioning Device Use

Comfort, postural support and/or maintenance, pressure management and function in a wheelchair are all influenced by the person's ability to physically move themselves by weight shifting and/or repositioning. If the person is unable to independently perform these movements, the use of power positioning devices such as tilt, recline and stand may be added to a power base to facilitate weight shifting or repositioning. The effectiveness of the addition of a power positioning device to a power wheelchair is related to if and how the device is used throughout the person's day. The studies below have examined how power tilt is used during the day, tracking parameters such as frequency and amplitude of position change.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Sonenblum & Sprigle 2011a USA Observational N=45	 Population: Mean age: 44.0 yr; Gender: males=33, females=12; Injury etiology: SCI=30, multiple sclerosis=4, cerebral palsy=4; Level of injury: cervical=29, thoracic=1; Level of severity: incomplete=15, complete=14, ineligible=1. Intervention: Wheelchair occupancy and seat position of participants were monitored for 1–2 wk using an accelerometer, occupancy switch and data logger. Outcome Measures: Type of wheelchair or cushion, Wheelchair tilt and recline angles, Uses of tilt-in- space, Wheelchair typical position, Tilt usage. 	 Complete wheelchair configuration was available for 38 participants, of which 29 could tilt their wheelchairs past 45°. On average wheelchairs were configured with approximately 100° of recline angle. Tilt-in-space was used for relieving discomfort (77%), pressure relief (73%), rest and relaxation (66%), posture (48%), and function (61%). Small and medium tilts were used more frequently than large and extreme tilts (p=0.000). Year in a wheelchair was negatively associated with tilt frequency (p=0.047) and diagnosis of SCI was associated with greater tilt frequencies (p=0.043). Participants with the ability to reposition spent significantly more time in a small tilt than those with no ability to reposition (p=0.030).
Sonenblum & Sprigle 2011b USA Observational N=45	Population: Mean age: 45 yr; Gender: males=15, females=30; Wheelchair: power=100%; Injury etiology: SCI=30 multiple sclerosis=4, cerebral palsy=4, other=7. Intervention: Monitored wheelchair occupancy and tilt position (typical position; time spent in small (0°-14°), medium (15°-29°), large (30°-44°), and extreme (>45°) magnitude tilts; tilt frequency; pressure-relieving tilt (i.e., moving into >30° for minimum of 1 min) (PRT) frequency) for 1-2 wk.	 77% of patients reported using their tilt- in-space systems for comfort, discomfort, or pain, 73% for pressure relief, 67% for rest/relaxation, 48% for posture, and 61% for function. Occupancy time median of 12.1 (range 4.1 - 24) hr/day. Each participants' typical position utilized a tilt position (median=8°; range 0°-47°). The median participant tilted every 27min, with PRTs performed less

Table 17. Use Patterns of Power Positioning Devices

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Outcome Measures: Data logger, accelerometer and occupancy switch.	 frequently (median participant performing one every 10h). 5. 81% of time for the median participant was spent in small tilt, 15% in medium, 1% in large and 0% in extreme tilt. 6. The size of tilt change (magnitude) for the median participant=70% small changes, 19% medium, 4% large and 0% extreme.
Sonenblum et al. 2009 USA Observational N=16	Population: Median age: 46 yr; Gender: males=11, females=5; Injury etiology: SCI=10, Other=6; Median time since injury: 6 yr. Intervention: Wheelchair use for 2 wk. Outcome Measures: Self-report related to reason for using tilt, Electronic logging of tilt utilization, Daily wheelchair occupancy time, Typical position, Time spent at different tilt angles tilt frequency, Pressure relieving tilt (PRT) frequency.	 Occupancy: mean of 11 hr/day, range 5.0-16.6; 6 subjects spent over 12 hr/day in wheelchair. Typical position: 10 subjects spent a majority of time in less than 15° tilt, 5 of whom spent 90% of time in this range; 5 spent majority of time in medium tilt range. Time spent in different degrees of tilt: eight reached an extreme tilt range. Median frequency of 3.1 tilts/hr. Tilt seldom used for performing PRT (median 1 PRT/7 hr). No significant difference in use based on self-reported purposes (p>0.10). Subjects reporting use of tilt for PRT did not perform more PRT (p=0.60) or use extreme tilts more than counterparts (p=0.67). Only one subject performed ≥2 tilt/hr.

In their 2009 study, Sonenblum et al. monitored the daily use of power tilt with 16 participants over a one-two week period of time with a secondary purpose of determining if regular pressure relieving tilts (PRT) were being used. PRT were defined as tilts greater than 30° for more than one minute, performed once per hour. The findings indicated great variability in wheelchair and tilt use between participants. This study also found that most participants varied greatly in how much tilt they used, and tilt positions changed frequently throughout the day even if it was only between two different positions within a small range. Participants identified the most common purposes for using tilt as being for comfort/discomfort/pain and rest/relaxation.

In a separate study, Sonenblum and Sprigle (2011a and 2011b) found similar results to the above study in regard to wheelchair occupancy and great variability in the amplitude, duration and frequency of tilt use. All studies found that people spent the majority of time in small to medium tilt position with infrequent pressure relieving tilts (i.e. greater than 30° of tilt). The size of the tilt change (magnitude) was reported to be predominantly small (0-14°) but with a range of frequencies in tilt use, suggesting that some people make small changes in position using tilt but are not using the full range of position changes available in the devices.

Conclusion

There is level 5 evidence (three observational studies, Sonenblum et al. 2009, Sonenblum & Sprigle, 2011a and Sonenblum & Sprigle 2011b) suggesting that on a daily basis, power positioning devices are used for a variety of reasons but predominantly in the small ranges of amplitude, and with great variability of frequency and duration.

Patterns of use for power positioning devices are variable but typically in small ranges of amplitude, with the primary reasons for use being discomfort and rest.

5.0 Seating Equipment for Wheelchairs

In addition to the multiple features available in wheelchair frames, the seating equipment used in the wheelchair must also be considered. Seating equipment includes back supports, wheelchair cushions, head supports, footsupports and any other supports that contact the person's body. Seating equipment is critical because it effects postural alignment, comfort, function and pressure management. This section reviews research related to the effects of seating equipment and its set-up on posture and postural alignment, and on functional tasks. Cushions comparisons of commercially available and custom contoured cushions are researched with the foucs being on trying to identify the optimal cushion characteristics for managing pressure, comfort and postural alignment. The final subsection reviews research related to changes in pressure in static sitting and dynamic sitting.

The effect of the seating equipment on the client's posture and pressure is often assessed in part using pressure mapping. This clinical tool is introduced first here as many of the studies in the subsequent sections use pressure mapping as one of their measurement tools.

5.1 Pressure Mapping Used in SCI

Pressure mapping technology has been available for many years but remains controversial in its use and interpretation from both clinical and research perspectives (Jan & Brienza 2006). Pressure mapping systems measure interface pressure. Pressure is defined as force over area (Gutierrez et al. 2007). Interface pressure is defined as the pressure that occurs at the interface between the body and the support surface (Barnett & Shelton 1997).

A pressure mapping device is an array of sensors contained in a flexible mat that measure interface pressure between the user and the support surface. The pressure values and surface contact area measured by the sensors is displayed in a colour-coded image on a computer screen, which includes a numerical value at each sensor location on the image. The clinician must determine the location of bony prominences on the image through manual palpation (Jan & Brienza 2006).

There are several factors that confound the use and interpretation of pressure mapping data. Interface pressure is only one of many contributing factors to the development of pressure ulcers. Some authors caution that the relationship between interface pressure and pressure ulcer incidence has not been studied well enough (Brienza et al. 2001), and that other contributing factors (extrinsic: skin moisture, friction, shear; and intrinsic: nutrition, age, arterial pressure) must also be taken into consideration (Rondorf-Klym & Langemo 1993; Barnett & Shelton 1997; Shelton et al. 1998). Subject variability, such as body weight, muscle tone, body fat content and skeletal frame size also influences interface pressure (Barnett & Shelton 1997; Shelton et al. 1998; Hamanami et al. 2004). The subject themselves influence interface pressure in terms of how they get onto the support surface as well as how they position themselves on that support surface (Hanson et al. 2006; Shelton et al. 1998). Time is also a confounding factor. Pressure applied between the surface and the subject changes over time (Hanson et al. 2006). Interface pressure is impacted by both magnitude and duration (Sonenblum & Sprigle 2011). Studies are suggesting that high pressure over a short period of time and less intense pressures over a longer period of time have similar risk in terms of potential skin damage (Kernozek & Lewin 1998; Stinson et al. 2003; Barnett & Shelton 1997). This time factor has also caused considerable controversy in how long a client should sit on the pressure mat to obtain a reliable reading of pressure (Kernozek & Lewin 1998; Stinson & Porter-Armstrong 2007; Eitzen 2004).

Pressure mapping systems themself are a confounding factor as they are highly dependent on material properties of the pressure transducer, soft tissue and the support surface, which may cause variability in data output. "Pressure mapping equipment may, in itself, cause several methodological weaknesses. Size of sensor mat, the number of sensors, and the sensitivity of the system will influence the resolution, accuracy, reliability and replicability of the measured pressure values." (Eitzen 2004, p. 1137).

All of these confounding factors contribute to the difficulty in interpreting the results of pressure mapping data collection. Since there is much variability between data collected for each client, an absolute threshold of pressure values has not been identified (Jan & Brienza 2006; Brienza et al. 2001). "Research has not identified a general interface pressure threshold below which pressure ulcers will not develop...There is no proven relationship between 32 mmHg threshold and pressure ulcer susceptibility" (Jan & Brienza 2006, p. 33-34). Several articles point out the need to use caution when interpreting quantitative measurements from different pressure mapping systems, as there are no industry standards in terms of data output for these systems (Ferguson-Pell & Cardi 1993; Hanson et al. 2006; Barnett & Shelton 1997; Eitzen 2004). "The gage pressure values generated by the system should be used with caution. Valid comparisons can be made between one surface and another for a single user. It is suggested that interface pressure measurement is better for identifying inappropriate support surfaces than for determining appropriate ones." (Jan & Brienza 2006, p. 33)

The critical parameters for an interface pressure measurement system include: overall mat size (smaller pads may not capture distribution of tissue loading), flexibility of the mat so it can conform to the deep contours of a cushion as the client settles into it, resolution (number of sensors per square inch – more sensors improve reliability), accuracy and repeatability (Barnett & Shelton 1997; Eitzen 2004).

The type of data used is also important. While clinicians tend to use the colour-coded image, researchers depend more on the numerical data. The most commonly used numerical data is maximum pressure, defined as the highest individual sensor recorded as a single value, usually seen at a bony prominence. Use of this single measurement value is limiting, as there is no indication of number of peak pressures, the size of the peak pressures or the average pressure for the entire surface. The other commonly used data measure is average pressure, which is defined as the mean, or average, of all sensor values (Shelton et al. 1998). Many researchers believe that "interface pressure data should only be used for relative judgments between surfaces tested under the same conditions" (Shelton et al. 1998, p. 33). Stinson et al. (2003) identified that controversy exists over stability of the average pressure values versus the maximum pressure values as a measure for research.

The inter-rater reliability of interpreting pressure mapping data output was evaluated by Stinson et al. (2002). The study used Occupational Therapy students with little/no experience in

pressure mapping system use and Occupational Therapists (OT) with experience in use. Both groups ranked pressure map images from different cushions from best to worse. Significant agreement was noted for students (p<0.001) and experienced OTs (p<0.001), however it was noted that students experienced greater difficulty ranking the group of pressure maps done on mid-high-pressure reduction cushions. Inter-rater reliability indicated perfect agreement of modal ranking for OT students and experienced OTs. In comparing pressure map ranking with numerical ranking agreement was found to be perfect for maximum pressure data (w=1.000) and near perfect for average pressure data (w=0.9). Stinson et al. (2002) concluded that: a) Pressure mapping systems users can reliably use pressure maps to guide intervention; b) Visual Interpretation of pressure maps is as reliable as the use of numerical data from pressure map systems.

In 2007, Stinson & Porter-Armstrong completed another study which evaluated whether using just colour coding is an appropriate method of assessment compared to the use of the numerical output of average and maximum pressure values using 27 subjects with Multiple Sclerosis (15 wheelchair users and 12 non-wheelchair users). Visual ranking of colour coded images was correlated with average pressure and with maximum pressure for each pressure mapping image. The author suggests using a combination of the numerical values with the visual image for interpretation. The use of visual interpretation alone may be helpful only in eliminating inappropriate cushions with extremes of pressure. Pressure mapping can be a helpful adjunct to clinical judgment as there are other contributing factors besides pressure in wound development that need to be considered in the provision of appropriate seating surfaces (Stinson & Porter-Armstrong 2007). Stinson and Porter-Armstrong (2007) results were as follows: a) Low to little correlation between visual ranking and average pressure on all six cushions for wheelchair users; no statistical significance was found b) Statistical significance found for visual ranking and maximum pressure for wheelchair users on foam (p<0.005) and polyester fiber (p<0.01) but no significance found on any other cushions c) Areas of maximum pressure can easily be identified on the colour code pressure image and therefore are used as bench marks when visually comparing surfaces for pressure distribution d) Sole reliance on visual interpretation of pressure maps may lead to inappropriate cushion provision.

While there are challenges in interpreting the values, the effectiveness of pressure mapping systems for education of clients in terms of visual feedback for proper pressure relief techniques, impact of postural changes and proper cushion set up, has proven valuable (Henderson et al. 1998; Jan & Brienza 2006).

Many studies throughout the remaining sections have used pressure mapping to assist in identifying the levels of in interface pressure related to posture and positions as well as changes in postures in positions. The reader is asked to keep the above considerations in mind when reviewing the following studies that use pressure mapping.

Summarized Level 5 evidence studies:

The following level 5 evidence studies have been reviewed, and the overarching findings from the studies are highlighted in this section. As noted at the start of this chapter, these types of studies are not included in the discussion or in the conclusions.

Taule et al. (2013) used an X-Sensor interface pressure mapping system to study the interface pressure of 75 people with a spinal cord injury (paraplegia = 40, tetraplegia = 35) in relation to demographic factors, level and completeness of injury, history of pressure injuries, and lifestyle factors. The authors identified satisfactory seating pressure as less than 100 mmHg and unsatisfactory seating pressure as more than 100 mmHg. A simple logistic regression (univariate) model revealed that the strongest predictor variables for unsatisfactory seating pressure ulcer (p=0.001), followed by type of wheelchair (p=0.007). The

study authors reported use of a manual wheelchair was almost five times more likely to produce an unsatisfactory seating pressure, and patients' level of injury (p=0.05) with people with paraplegia 3 times more likely to have unsatisfactory seating pressure than tetraplegia. The authors identified this significant relationship between unsatisfactory sitting pressure and the type of wheelchair and having a history of pressure ulcers with 52% of the 75 study participants. Howeverthe results of the study are based on the conclusion drawn at the start of the study related to satisfaction or dissatisfaction with seating position/pressure; the methods used to make the decision was not clear. Items were dichotomized however, the methods by which factors such as cushion and wheelchair type or co-morbidities were considered and/or weighted in that determination of satisfactory or unsatisfactory sitting pressure was not indicated.

5.2 Effects of Seating Equipment Set-up on Posture and Postural alignment

The loss of voluntary trunk stability and the postures imposed by the configuration of the wheelchair contribute to the development of spinal deformities and an abnormal sitting posture in the SCI population. These changes result in a kyphotic C-shaped thoracolumbar spine, extended cervical spine, flattened lumbar spine and posteriorly tilted pelvis (Hobson & Tooms, 1992; Janssen-Potten et al. 2001). Prolonged sitting results in application of pressure over bony weight-bearing prominences and are cited as a major contributing factor to the development of pressure sores.

Country Research Design Score Total Sample Size	Methods	Outcome
Shields & Cook 1992 USA Prospective Controlled Trial N=36	Population: <i>SCl group:</i> Age range: 21-38 yr; Gender: males=13, females=5; Weight range: 45-66 yr; Height range: 158-177 cm; Level of injury: paraplegia=12, tetraplegia=6; Chronicity=chronic; <i>Control</i> <i>group:</i> Age range: 21-52 yr; Gender: males=7, females=11; Weight range: 51- 71 kg; Height range: 156-178 cm. Intervention: Lumbar support thickness adjustment (0, 2.5, 5, 7.5cm). Outcome Measures: Highest and lowest seated buttock pressure, Hip angle.	 In the able-bodied group, only the 5 cm and 7.5 cm lumbar support thicknesses caused a decrease in highest seated buttock pressure. The adjustment of lumbar support thickness did not influence highest seated buttock pressure in the SCI group. The area of highest seated buttock pressure was significantly higher in SCI than control group. SCI had a reduced pelvifemoral angle for all lumbar thickness adjustments.
Hobson 1992 USA Prospective Controlled Trial N=22	 Population: SCI group: Mean age:40.9 yr; Gender: males=10, females=2; Mean weight=59.8 kg; Level of injury: paraplegia=7, tetraplegia=5; Severity of injury: complete=12; Mean time since injury=19.5 yr; Able-Bodied group: Mean age: 39.2 yr; Gender: males=6, females=4. Intervention: Nine typical wheelchair sitting postures. Outcome Measures: Tangentially induced shear, Pressure distribution- Oxford Pressure Monitor Device. 	 Mean maximum pressure was on average 26% higher in the SCI group versus the able-bodied group. Forward trunk flexion reduced the average pressure for both groups; however, SCI group encountered a 10% increase in pressure at the initial 30° of forward flex before a reduction occurred. SCI subjects had a mean peak pressure gradient that was 1.5-2.5 higher than able-bodied subjects. Maximum decrease of pressure gradient from a neutral position happened after the backrest reclined to 120°.

Table 18. Effects of Seating Equipment Set-up on Posture and Postural Alignment

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
		4. When a sitting position change occurred, a similar shift to the anterior/posterior midline location of maximum pressure was experienced in both groups. From neutral, a forward trunk flexion at 30° and 50° produced a 2.4 and 2.7cm posterior shift. When the backrest reclined to 120°, the greatest posterior shift occurred at 6cm.
Hobson & Tooms 1992 USA Prospective Controlled Trial N=22	Population: <i>SCI</i> (<i>n</i> =12): Level of injury: paraplegia=7, tetraplegia=5; <i>Able-bodied</i> (<i>n</i> =10). Intervention: Three standardized sitting postures: P1M, neutral position; P1R, trunk bending; P2, forward trunk flexion. Outcome Measures: Spinal and pelvic alignment.	 Disabled group on average has more lumbar lordosis in upright sitting position compared to the normal group. Person with a SCI will sit in neutral posture with posteriorly tilted pelvis (- tilted on average 15° more than non- injured), forward trunk flexion (30° from neutral posture), forward rotation of the pelvis (8° normal and 12° SCI). In neutral seated posture posterior pelvic tilt causes ITs of SCI to be displaced anteriorly on average 4cm. Kyphotic spinal deformity occurs mainly in thoracolumbar/thoracic spine with compensation in cervical spine - implications for backrest height and lumbar pads. Changes in angle of pelvis and IT location have implications for tissue distortion and/or mechanical abrasion of buttock tissue.
Janssen-Potten et al. 2001 Netherlands Case Control N=30	Population: High SCI (12-8, n=10), Low SCI (T9-12, n=10), Able-bodied controls (n=10). Age range: 25-53 yr; Gender: males=28, females=2; Height range: 1.7- 1.9 m; Weight range: 52.1-87.3 kg. Intervention: Standard chair and chair with 10° forward seat incline. Outcome Measures: Pelvic tilt, Center of pressure displacement (COP), Muscle activity, Reaching task.	 There was no significant influence of incline on pelvic tilt in any group. Able-bodied controls had a significantly larger reaching position than the SCI groups (p<0.001). The COP was not significantly different between the two chairs, or the groups.
Mao et al. 2006 Taiwan Pre-Post N=17	Population: Mean age: 35.4 yr; Gender: males=10, females=7; Level of injury: C5- T11; Chronicity=chronic. Intervention: Adjustable seating system with lateral trunk supports (LTS). Outcome Measures: Spine radiographs, Cobb angles, Relative change in angle.	 LTS improved spinal alignment in frontal plane. LTS reduced lumbar angle in sagittal plane resulting in more erect posture.
Alm et al. 2003 Sweden Pre-Post N=30	Population: Mean age: 25.8 yr; Gender: males=30, females=0; Injury etiology: complete C5-C6 tetraplegia. Intervention: Documentation and evaluation of wheelchair sitting (i.e., type of wheelchair, seat angle, backrest height, type and height of cushion).	 In SCI subjects, the pelvo-femoral angle was statistically significantly smaller in the wheelchair as compared to the standardized surface in relaxed (p<0.001) and upright (p=0.005) sitting positions. In the relaxed sitting position, there were no significant differences among

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Outcome Measures: Pelvo-femoral angle (deg), Pelvic tilt (deg), Upper body height. Frontal trunk alignment, Pelvic obliquity.	 SCI patients in the pelvic anterior tilt between the standardized surface and wheelchair, regardless of seat angle. In the upright sitting position, the pelvic anterior tile was statistically significantly less (p=0.004). In SCI patients, the mean vertical acromion-trochanter major distance in the sagittal plane was statistically significantly larger in upright than in the relaxed sitting position on both the standardized surface (mean increase: 5%, p<0.001) and in the wheelchair (mean increase: 4% p=0.001). Results showed a statistically significant decrease in mean heights in wheel chair for both relaxed (p<0.001) and upright (p<0.001) sitting positions. For SCI patients, there were no significant differences observed in the horizontal C7 deviation in the frontal plane between relaxed and upright sitting positions, for either the standardized surface or in wheelchair.
Bolin et al. 2000 Sweden Pre-Post N=4	Population: Mean age: 25.8 yr; Gender: males=4, females=0; Injury etiology: complete thoracic spinal cord injury (SCI), Mean time since injury: ≥2 yr. Intervention: A new wheelchair prescription with features to support sitting, stability, and improve balance, pelvic posterior tilt. Outcome Measures: Modified Functional Reach Test (MFRT), Functional Independence Measurement (FIM), Ashworth Scale (AS).	 There were no changes in the level of spasticity observed for ³/₄ participants. One participant perceived a decrease in his level of spasticity. Except for improved balance in one participant, the MFRT did not show any significant differences in ³/₄ participants' balance. Two self- perceived an improvement in balance and one expressed a further deterioration in balance. No changes were observed in respiration for two participants; two perceived an improvement and one perceived deterioration. Two participants stated their wheelchair propulsion improve, even though this was not supported by Cooper's test or uphill slope propulsion. Wheelchair skills improved for one participant and remained unchanged for two participants. Three participants perceived their wheelchair skills to be improved.

Summarized Level 5 evidence studies:

The following level 5 evidence studies have been reviewed, and the overarching findings from the studies are highlighted in this section. As noted at the start of this chapter, these types of studies are not included in the discussion or in the conclusions.

Hong et al. (2016) described levels of comfort using the Tool for Assessing Wheelchair discomfort (TAWC) for rigid and sling style back supports. 131 participants rated their discomfort for different body regions (back, neck, buttocks, legs, arms, feet and hands) for their current back support. The authors found a trend towards more discomfort reported for rigid back supports; however, they did not account for the fit and positioning of the participants in the rigid back support which may influence discomfort levels.

Discussion

Shields and Cook (1992) compared the effects of different lumbar support thicknesses on seated buttock pressure. Results of the study suggest that use of a lumbar support was not effective in reducing seated buttock pressure areas in individuals with chronic (≥three yr) SCI. Subjects with SCI were positioned with the pelvis placed as far back in the chair as possible, however, the chronic SCI group had significantly reduced pelvifemoral angle (hip flexion angle) for all lumbar support conditions as compared to the nondisabled group. SCI subjects were not able to sit with an initial hip flexion angle or anterior tilted pelvis as compared to control subjects likely due to shortened hamstrings or hip extensor musculature or structural changes of the spine in chronic SCI.

Hobson and Tooms (1992) investigated the presence of abnormal spinal/pelvic alignment(s) in the SCI population and the impact of the typical seated posture in a wheelchair. On average, the disabled group had more lumbar lordosis in the upright sitting position compared to the ablebodied group. Persons with a SCI tended to sit in a neutral posture with a posteriorly tilted pelvis and tilted on average 15° more than able-bodied group. A forward trunk flexion to 30° from neutral posture resulted in forward rotation of the pelvis – 8° in able-bodied compared with 12° in the SCI group. Lower spinal flexion occurred in the SCI group's lumbar sacral joint with negligible movement at the sacroiliac joint. In a neutral seated posture, the posterior pelvic tilt caused the ischial tuberosities (IT) of the SCI group to be displaced anteriorly four cm, on average. The angle and rotation of the pelvis and the ischial tuberosity location and slide have implications for tissue distortion and/or mechanical abrasion of buttock tissue.

Use of radiographic evidence to measure spinal alignment of individuals in a seated position was investigated in the study by Mao et al. (2006). The effects of lateral trunk support on a SCI's individual frontal and sagittal spinal alignment in the seated position were considered. Results showed that lateral trunk supports significantly improved spinal alignment in the frontal plane regardless of the severity of scoliosis. Lateral trunk supports also resulted in a more erect seating posture by reducing the lumbar angle in the sagittal plane. Improved head and trunk alignment with reduced muscular effort was also enhanced by the lateral trunk supports.

Hobson (1992) completed work on the comparative effects of posture on pressure and shear at the body-seat interface. Postures typically assumed by wheelchair users were studied. The pressure distribution findings suggest that individuals with SCI have higher maximum pressures for all postures studied than the able-bodied group. Maximum pressures can be reduced with postural changes – forward flexion to 50°, backrest recline to 120° and full body tilt.

Janssen-Potten et al. (2001) examined the effect of seat tilting on pelvic tilt, balance control and postural muscle use. Providing a standard wheelchair with a cushion creating 10° forward inclination of the seat had no effect on pelvic tilt for persons with or without a SCI. The study did not reveal a difference in pelvic tilt because of seat manipulation. However, the difference between pelvic position at rest and in the forward-reaching position was significantly greater in non-sensorimotor-impaired persons than in persons with SCI. The second purpose of the study

was to determine if the forward inclination of the seat impacts balance control and alternative muscle use in the thoracic SCI Group. There were no significant changes in centre of pressure displacement between the standard chair condition and the forward inclined seat condition for all three groups (high thoracic, low thoracic and able-bodied). Review of the kinematics combined with the electromyography data did not provide evidence for development of a protocol for wheelchair prescription for pelvic positioning in persons with a SCI.

The effect of foot support height on ischial tuberosity pressure for 17 people with paraplegia SCI who used manual wheelchairs was examined by Tederko et al. 2015. A standard study wheelchair was used with the seat horizontal and the seat surface to back angle being set at 90°; the cushion was five cm thick foam to allow pressure changes to be observed. Foot supports were raised 10% and 20% of the participants' fibula length using 5 mm thick mats was placed under the feet. Results of interface pressure mapping using the X-Sensor system indicated significant differences between each raised foot support position for all variables studied. As the foot support position was raised, the contact surface decreased and the average pressure at the IT increased significantly; authors report observations of raising foot supports also raising thighs off the seat surface which would contribute to reductions in contact surface noted in pressure mapping. The authors note that they did not examine coccygeal pressure changes or changes in the pelvic position with the raising of foot supports or differences on differences on different seat cushions.

Conclusion

There is level 2 evidence (from one prospective controlled trial and one pre-post study; Hobson & Tooms 1992; Mao et al. 2006) that the typical SCI seated posture has spinal and pelvic changes/abnormalities.

There is level 2 evidence (from two prospective controlled studies; Hobson 1992; Shields & Cook 1992) that in sitting postures typically assumed by people with SCI, maximum sitting pressures are higher than in able-bodied people.

There is level 4 evidence (from one pre-post study; Mao et al. 2006) that use of lateral trunk supports in specialized seating improve spinal alignment, reduce lumbar angles and reduce muscular effort for postural control.

There is level 2 evidence (from one prospective controlled trial; Shields & Cook 1992) that the use of lumbar supports does not affect buttock pressure.

There is level 3 evidence (from one case control study; Janssen-Potten et al. 2001) that there is no difference in balance and postural muscle control between static positions on a level surface and a 10° forward incline for people with SCI; the pelvic position does not change as compared to able-bodied participants.

Individual attention to spinal/pelvic posture and positioning for SCI clients is essential for appropriate wheelchair prescription and set-up.

Use of lateral trunk supports in specialized seating improve spinal alignment, reduce lumbar angles and reduce muscular effort for postural control.

5.3 Impact of Seating Equipment on Functional Tasks

Due to the reduced physical abilities of persons with SCI, they require wheelchair and seating equipment. This equipment includes wheelchair frames and specialized seating components including back supports, cushions, armrests, and footrests. The relationships between wheelchair configuration, sitting balance and the ability to perform functional activities in persons with a SCI have been studied.

Author Year Country Research Design Total Sample Size	Methods	Outcome
Kamper et al. 1999 USA Prospective Controlled Trial N=13	Population: Age range: 27-44 yr; Gender: males=13, females=0; Height range: 160-191 cm; Level of injury: paraplegia=4, tetraplegia=4, able- bodied=5; Time since injury range: 3-29 yr; Chronicity=chronic. Intervention: Controlled perturbation applied while in wheelchair. Outcome Measures: Use of upper extremities to stabilize; Instability onset time; Center of pressure movement (COP), COP state + position + velocity (DFLCOP); Body segment movements.	 Able-bodied subjects sustained stability for all perturbations. Platform angles where stability was initially lost was lowest for subjects with tetraplegia (p<0.001). When instability occurred, the time to attain DFLCOP threshold was related to the onset of instability (r=0.95). The sequential relationship between threshold and instability was not as strong (r=0.90). Lower and upper torso rotation was significantly more common in the SCI group, as compared to the able-bodied group (p<0.05). When imbalance occurred, SCI patients tended to rotate the pelvis and lower torso in the direction of the fall before the rest of the body.
Janssen-Potten et al. 2002 Netherlands Case Control N=30	 Population: Mean age: 39.4 yr; Gender: males=27, females=3; Mean height: 177 cm; Mean weight: 73.5 kg; Level of injury: thoracic=10, lumbar=10; Able-bodied=10. Intervention: Perform balance changing reaching movements with a solid footrest or an elastic footrest. Outcome Measures: Reaching distance, Time to performing reaching task, Center of pressure displacement (COP), Muscle activity, Center of mass (COM). 	 SCI subjects reached slower with the elastic footrest (p<0.01) than the able-bodied group. In SCI subgroups, reaching task technique differed between two footrests (p<0.05). Solid footrests worked better for the lumbar SCI group, indicated by a 4% decrease in backward COP displacement. Elastic footrests gave thoracic SCI group better balance, indicated by a 46% increase in initial COP background movement. Able-bodied and lumbar SCI groups experienced a decrease in forward acceleration of COM with elastic footrest. Able-bodied subjects experienced muscle activity alterations when footrests were switched, but SCI subjects did not.
Janssen-Potten et al. 2000 Netherlands Case Control N=30	Population: <i>High SCI group:</i> Age range: 24-43 yr; Gender: males=10, females=0; Level of injury: paraplegia=10; <i>Low SCI group:</i> Age range: 23-55 yr; Gender: males=9, females=1; Level of injury: paraplegia=10; <i>Able-bodied group:</i> Age	 No significant difference in actively controllable reach in control group or in low SCI group with tilting the chair or reclining the backrest. The low SCI and able-bodied groups had a significant increase in center of pressure displacement

Table 19. Impact of Equipment on Functional Tasks

Author Year Country Research Design Total Sample Size	Methods	Outcome
Total Gample Gize	range =27-41 yr; Gender: males=10, females=0. Intervention: Four different configured chairs: 7° (T7) and 12° (T12) tilt angle, 22° back recline (R22) and 10° standard chair configuration (S). Outcome Measures: Maximal unsupported reaching distance; Muscle activity using an Electromyography (EMG) (serratus anterior, pectoralis major, oblique abdominal); Center of pressure displacement (COP).	 when the standard chair was compared to the other chairs. 3. The high SCI group did not experience a change in centre of pressure displacement. High SCI were unable to control shift in body mass larger than one induced by arm movement.
Hastings et al. 2003 USA Pre-Post N _{initial} =17, N _{Final} =14	Population: Mean age: 42 yr; Gender: males=12, females=2; Mean weight: 78 kg; Mean height: 178 cm; Level of injury: paraplegia=4, thoracic=10; Severity of injury: AIS: A=12, B=2; Chronicity: chronic. Intervention: Three manual wheelchairs with different configurations: (S1) EandJ Premier, (S2) Quickie Breezy, (T) Test configuration chair Quickie TNT, with posterior seat incline and low backrest perpendicular to the floor. Outcome Measures: Shoulder and neck alignment; Pelvic tilt. All determined via digital photos at rest and vertical reach.	 There was less forward head position measurement with T than with S1 (p=0.008) and S2 (p=0.036). Humeral flexion ability was significantly higher in T compared to S2 (p=0.036), but not S1. In the T chair, subjects could reach a significantly greater height above the wheelchair seat base than in the S1 (p=0.005) and S2 (p=0.002). Wheelchair with a positive seat slope of 14°, acute inside backrest angle, and relatively low back rest (meets lowest rib) superior to standard wheelchairs in supporting more vertical postural alignment and greater reach.
Gabison et al. 2017 Canada Post-Test N _{initial} =17 N _{final} =15	Population: Reachers Group (n=8): Mean age= 46.5 yr; Gender: males=5, females=3; Level of injury: C5-T12; Mean time since injury= N/R. Non-Reachers Group (n=9): Mean age= 40.0 yr; Gender: males=9, females=0; Level of injury: C4- L4; Mean time since injury= N/R. Intervention: To compare trunk function and offloading of ischial tuberosities of participants who were divided into two groups depending on their ability to engage in multidirectional reach test (MDRT): Reachers, or Non-Reachers. A sensimat [™] pressure mat was placed under wheelchair cushion to evaluate pressure offloading during sitting and usual activities for 2 hr period. Outcome Measures: isometric Trunk strength using hand held dynamometer; offloading time measured using Sensimat [™] interface pressure mapping system.	 The Reachers had significantly higher trunk strength compared to the Non-Reachers (p<0.05). Offloading times over the left and right ischial tuberosities were lower in Non-Reachers when compared with Reachers, however the results were statistically significant only for offloading over the right ischial tuberosity (p=0.029. There was no correlation between trunk strength and pressure offloading times for both groups (p>0.05).
May et al. 2004 Canada Post-Test N=27	Population: Mean age: 30.3 yr; Gender: males=21, females=6; Time since injury range: 1-22 mo. Intervention: Three different wheelchair back supports: sling upholstery-standard	 Only reaching on the forward vertical reach task was found to differ significantly between back supports (p=0.01). Subjects reached higher with using the

Author Year Country Research Design Total Sample Size	Methods	Outcome
	back support (SB), Jay J2-replacement of standard back support (RSB), Pindot PaxBac - attachment to standard back support (ASB). Outcome Measures: Satisfaction Questionnaire, Mean scores of four functional tasks performed twice each: Time forward wheeling, Forward vertical reach, ramp ascent, 1-stroke push.	 RSB, as compared to the SB (p=0.015). Subjects were most satisfied with the RSB (p=0.017), and least satisfied with the ASB. RSB was rated most comfortable and as having the best appearance (p=0.018).
Sprigle et al. 2003 USA Post-test N _{Initial} =22, N _{Final} =20	Population: Age range: 18-64 yr; Gender: males=19, females=1; Chronicity: sub-acute, chronic. Intervention: Six configurations containing 3 types of cushions (segmented air, contoured viscous fluid/foam and air/foam), and 2 of 3 backrests (T12, inferior scapular angle and scapular spine). Outcome Measures: Reaching tasks: functional reach task, bilateral reach task, unilateral reach task; Seated posture.	 Cushion type and backrest height did not significantly influence reach or posture.

The above studies demonstrate aspects of equipment options and the impact on the SCI person's functional abilities, specifically reaching and controlled perturbations.

In the Gabison et al. (2017) study, there was not a significant correlation between isometric trunk strength and ischial offloading. However, it reinforces the importance of assessing reaching abilities and trunk muscle activation for development of rehabilitation strategies for offloading pressure of the bilateral ischial tuberositis in those SCI individuals that lack sufficient trunk strength.

No single back support option studied by May et al. (2004) consistently facilitated performance in four functional tasks (i.e., forward wheeling, forward vertical reach, ramp ascent, and 1-stroke push). However, reaching activity differed significantly among back supports with SCI persons able to reach higher when using the Jay2 back (p=0.01) compared to the sling back (p=0.015).

Janssen-Potten et al. (2000) studied balance control and postural muscle use with four different chair configurations manipulating tilt angle of the chair and reclining angle of the backrest. No significant difference in controlled reach was found in controls or in subjects with low SCI. Sitting balance and ability to control displacement of arms and trunk during reaching improved in all chairs compared to the standard chair. Among SCI subjects with high levels of tetraplegia, sitting balance did not improve because they were unable to control body mass shift.

In a study of the effects of footrests on the sitting balance in individuals with paraplegia found that absence of a solid footrest did not decrease maximal unsupported reaching distance. Solid footrests contribute to sitting balance in persons without SCI and persons with lumbar SCI but not for persons with thoracic SCI. Persons with thoracic SCI can benefit from an elastic footrest to perform activities of daily living. Changes in muscle activity were noted when a solid footrest was replaced by an elastic footrest in persons without SCI but not in persons with SCI

performing activities of daily living. Footrest conditions affect how activities of daily living are performed but not the range of activities (Janssen-Potten et al. 2002).

Kamper et al. (1999) studied the lateral postural stability of seated individuals with SCI in a dynamic environment. All SCI subjects were stable under static conditions but became unstable in a dynamic environment. Instability of SCI subjects resulted from inability to prevent rotation of the pelvis and lower torso. Rotation of the lower torso to upper torso was significantly greater in SCI subjects. The kinematics responses of able-bodied and SCI revealed that rotation of the lower torso and pelvis was greater in the SCI subjects and rotation in direction of fall preceded the rest of the body. All SCI subjects could have benefited from lateral support.

Hastings et al. (2003) investigated the postural alignment and maximal reach of individuals with C6-T10 level of SCI. The authors found that when sitting in a chair with a positive seat angle of 14° and with a low back support perpendicular to the floor, the subject's vertical postural alignment was improved as compared to standard chairs. The alternate chair configurations also produced greater reach ability.

The upper extremity function of wheelchair users is impacted by seated posture and trunk control. Finding a balance between adequate trunk support and trunk mobility can impact functional ranges of motion and upper extremity function. Sprigle et al. (2003) revealed that upper extremity reach for wheelchair users was affected by posture but not influenced by the cushion type or backrest height. A wheelchair user's posture is more functionally important than the supportive devices used for therapists prescribing cushions and backrest height. A posterior tilted pelvis enhances function and the position of pelvic tilt is an important predictor in measures of reach. The torso angle impacted bilateral reach, not unilateral reaching tasks. Monitoring of posture is an important factor when assessing seating and function of wheelchair users.

Conclusion

There is level 3 evidence (from three repeated measures studies and one case control study; May et al. 2004; Hastings et al. 2003; Sprigle et al. 2003; Janssen-Potten et al. 2002) to support the evaluation of functional performance to facilitate the decision making process for assessment and prescription of wheelchair and seating equipment options providing objective information about performance.

There is level 4 evidence (from one post-test study; Gabison et al. 2017) to suggest that reaching does not consistently provide offloading at the ischial tuberosities and not equaly between left and right.

There is level 2 evidence (from one prospective controlled trial and one case control study; Kamper et al. 1999; Janssen-Potten et al. 2000) to support that pelvic positioning especially related to pelvic tilt and the relationship between the pelvis on the trunk, affects upper extremity and reaching activities, performance of activities of daily living and postural stability.

The set up and type of seating and wheelchair frame are critical to supporting the person's postural stability thereby effecting functional ability to reach and engage in pressure management strategies.

5.4 Seated surfaces

The seat cushion in a wheelchair has many roles depending on the indiivudal's unique needs. Primarily, the cushion's role is, to contribute to a functional and balanced posture and redistributing pressure away from the critical areas of the IT and the sacrum and re-distributing pressure over a larger contact area to reduce overall and peak pressures (Eitzen 2004). Bogie et al (1995) stated that 47% of pressure ulcers occur at the IT or sacrum and are therefore more likely to have been initiated while seated. Provision of a wheelchair cushion that redistributes pressure is an important prevention recommendation. Cushions should be evaluated based on postural support and stability provided, pressure redistribution capabilities, comfort, function temperature effects level of SCI, pressure redistribution abilities, transfer technique and lifestyle (Garber 1985; Makhsous et al. 2007a; Fisher et al. 1978; Seymour & Lacefield 1985; Sprigle et al. 1990). Many of the studies reviewed for this section compare different cushions in an attempt to identify the "best" cushion. One study explored how the intensity of the load when sitting on a cushion influences blood flow, which is thought to influence pressure injury risk.

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Author Year Country Research Design Score Total Sample Size	Methods		Outcome
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Crane et al. 2016 USA RCT Crossover PEDro=5 N=10	Population: Mean age= N/R; Gender: males=9, females=1; Level of injury: N/R; Mean time since injury= 20 yr. Intervention: Comparison of interface pressure between an off-loading cushion in three conditions: fully off-loading (C0- off), addition of the top well insert (C1- off), addition of both well inserts (C2-off) to a 10cm-high air flotation cushion (C3- float). The order of cushions was randomized for each participant with each trial being completed 5 times for 2 mintues each time. Risk of the pressure mat hammocking was accommodated. Sitting surface bony prominences weremanually palpated and located in relation to the pressure readings. Outcome Measures: Peak pressure index (PPI); Ischial tuberosity (IT) peak pressure; Dispersion Index; Contact Area; Average pressure using Interface Pressure Mapping.	2.	PPI averaged values ranged from a low of 39±18mmHg (C0-off) to a high of 97±30mmHg (C3-float));(C1 - 61±19, C2 -78±30). Differences between all conditions was significant at P<.001 PPI , IT peak pressure, dispersion index, were all significantly lower in C0, C1 and C2 than C3 but significantly higher for contact area and average pressure
Sonenblum et al. 2018a USA RCT Crossover PEDro=5 N=4	Population: Mean age= 42.0 yr; Gender: males=1, females=3; Level of injury: T2-T12; Mean time since injury= 15.8 yr. All participants had significant muscle atrophy at their sitting surface therefore were considered high risk for developing pressure injuries. Intervention: Participants buttocks' were scanned sitting in a FONAR Upright MRI. Scans were collected with the individuals' buttocks fully suspended without pelvic support and seated on 3 different wheelchair cushions: <u>Enveloping</u>	1. 2. 3.	All participants had similar buttock anatomy with significant muscle atrophy (muscle volume avg: 265 cm ³) and limited soft ticcue at the ischium (bulk tissue thickness ranged between 28 and 40 mm) Bulk tissue thicknesses at the ischium were reduced by more than 60% on Roho HP and Matrx Vi, and more variably (23–60%) on Java. Bulk tissue thickness under the greater trochanter was consistent acorss participants and cushions, ranging from

Table 20. Cushion Comparison

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	<u>cushions</u> : Roho HP, Matrx Vi; <u>Offloading</u> <u>cushion</u> : Java. Outcome Measures: Bulk tissue thickness, percent of gluteus coverage under the peak of the ischial tuberosity, muscle volume, tissue deformation, greater trochanter bulk tissue thickness measured using an MRI, sacro- coccygeal angle changes and Peak pressure Index using an IPM	 12-27mm in the loaded condition and displaced laterally in the loaded condition, Peak pressure indeces ranged varied across participants and cushions (50- 290mmHg) – lowest PPIs seen with the Java and highest on the MatrixVi. The gluteus maximus displaced superiorly and laterally on the Roho cushion, superiorly and laterally on the MatriVi, and was most similar to the unloaded condition on the Java, with the gluteau maximus not being loaded whiel sittign on the Java cushion.
Gil-Agudo et al. 2009 Spain RCT PEDro=5 N=48	 Population: Mean age: 42 yr; Gender: males=38, females=10; Mean weight: 67.6 kg; Mean BMI: 23.3 kg/m²; Level of injury: cervical=13, thoracic=35; Severity of injury: AIS A. Intervention: Use of interface pressure mapping to determine its utility in cushion selection. Comparison of cushions: 1) single compartment low profile air cushion; 2) single compartment, high profile air cushion; 3) dual compartment air cushion; 4) gel and firm foam cushion. Wheelchair set-up was normalized (hips, knees and ankles at 90°, seat parallel to floor, back perpendicular or tilted up to 10 °); air cushions all individually adjusted at set-up for each trial based on manufacturer instructions. Outcome Measures: Pressure mapping using the Xsensor to compare distribution of pressure (peak maximum pressure of entire map and peak pressure at ischial tuberosities (IT)) and contact surface (total contact area with readings greater than 60mmHg and less than 60mmHg) from a 1.5 min reading. 	 The interface pressure mapping system was useful for assessing the mechanical characteristics of this sample of cushions. The dual compartment air cushion had significantly lower peak maximum pressure across the mapping surface, and lower peak pressure in the area of the IT than other cushions evaluated in this study The gel and firm foam cushion had the highest mean pressure values (p<0.05 versus low-profile air, high-profile air, dual compartment air) but had significantly lower peak pressure values at the ITs over the single compartment, low profile air cushion; there were no statistically significant differences (p<0.05) in any variable between the single compartment air cushions - low and high profile. For surface variable measurements, the dual compartment air cushion had the largest total contact surface (p<0.05) compared to the three other cushions; the dual compartment air cushion had the lowest percentage of the total contact surface with pressure readings over 60mmHg (p<0.05) compared to the other three cushions); the dual compartment air cushion had the lowest contact surface with pressure readings over 60mmHg (p<0.05) except for the low profile single compartment air cushion (p=0.11). The cushion with the least favorable total contact surface was the single compartment low profile air cushion (p<0.05) compared to the other three cushions. The cushion with the largest surface area above the 60 mmHg threshold was the gel and firm foam cushion (p<0.05) compared to the other cushions.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Burns & Betz 1999 USA Prospective Controlled Trial N=16	Population: Mean age: 46 yr; Gender: males=16, females=0; Level of injury: tetraplegia=16; Severity of injury: AIS A=7, B=9. Intervention: Two static wheelchair cushions (dry flotation and gel) upright and at 45° tilt, compared to a dynamic cushion that was composed of two air bladders (H and IT) that alternated between inflation and deflation. Outcome Measures: Interface pressure at ischial tuberosities (IT) was assessed with Clinseat seating interface pressure sensor.	 When compared in the high-pressure condition, all cushions were significant (p<0.001), with means of 111 mmHg (dry flotation), 128 mmHg (gel), and 157 mmHg (dynamic). When compared in the low-pressure condition, only gel flotation (86 mmHg), and the dynamic cushion (71 mmHg), were significant (p<0.05). The IT had a significantly higher mean during IT bladder inflation of the dynamic cushion than the high- pressure position in the static cushions (p<0.01), with the dry flotation having significantly lower pressure than the gel cushion (p<0.01). The IT had significantly lower mean in the lower pressure position only for the dynamic cushion as compared to the gel cushion (p<0.01).
Garber 1985 USA Prospective Controlled Trial N=251	Population: Gender: males=207, females=44; Injury etiology: SCI=251 Intervention: Assessment of pressure distribution for seven cushions. Outcome Measures: Seated pressure distribution.	 No statistical results reported. The air-filled cushion (ROHO which was 1 of 2 used) produced the greatest pressure reduction in 51% of the subjects. A foam cushion (the stainless comfy hard cushion) was effective for only 18% of the subjects even though it was the second most frequently prescribed cushion. More subjects with tetraplegia received the ROHOs than subjects with paraplegia (55% versus 45%) while more paraplegic subjects were prescribed the Jay cushion (a combination of foam and flotation materials (19% versus 7%).
Makhsous et al. 2007b USA Cohort N=60	Population: Mean age: 37 yr; Gender: males=45, females=15; Level of injury: paraplegia=20, tetraplegia=20, and able- bodied=20. Intervention: Two 1-hr protocols. 1) Alternative-sitting position was altered every 10 min between normal and WO- BPS (partially removed ischial support and lumbar support). 2) Normal-normal posture and push-ups every 20 min. Outcome Measures: XSensor pressure mapping system measuring Interface pressure measures of total contact area, average pressure and peak pressure on backrest and anterior middle and posterior sections of the seat.	 Those with tetraplegia had a larger contact area at the anterior portion of the cushion, as compared to the other groups. The mean pressure over the whole cushion was significantly different for each group (p<0.001). Those with tetraplegia had the highest mean pressure during the WO-BPS posture, as compared to the other groups (p<0.001). The contact area of the posterior portion of the cushion and the peak interface pressure decreased in all groups, with the largest decrease in those with tetraplegia for the latter. The mean pressure on the anterior and middle portions of the cushion increased in all groups.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Population: Age range: 16-35 yr; Weight range: 40.6-72.5 kg; Injury etiology: SCI=10, healty control=10.	 At the posterior portion of the seat where ischial tuberosities are usually positioned, average pressure was higher for those with paraplegia (88.9 mmHg). Average push up time was 49 sec for those with paraplegia. Greatest pressure was seen under the soft tissue areas of most subjects; no significant differences between the cases and controls
Seymour & Lacefield 1985 USA Case Control N=20	available cushions and one experimental cushion were evaluated for each subject. Outcome Measures: Temperature and pressure effects for each cushion. Subjects were asked to rate each cushion as to cosmesis, handling and suitability for purchase.	 Temperatures were lowest for gel, water and air cushions and highest for alternating pressure and foam cushions. SCI group - Greatest pressure under a bony area occurred most often with the Spenco cushion (90.10 mmHg); controls - it occurred most often with the Tri-pad (89.20 mmHg) indicating that these cushions did not compare favorably to others. There was wide variability in pressure measurements in individual subjects (SD=12.21 mmHg). However, air filled (Bye Bye Decubiti) had the best pressure readings. Cosmesis (83%) and handling (73%) were related to purchase decisions.
Vilchis-Aranguren et al. 2015 Mexico Pre-Post N=16	Population: Mean age: 31.8 yr; Gender: males=9, females=7. Intervention: Participants were administered a prototype wheelchair cushion designed to adjust the anthropometry of the user's ischio-gluteal area and prevent pressure ulcer formation. Participants were assessed at baseline and at 2 mo. Outcome Measures: Functional independence measure (FIM), Modified ashworth scale (MAS), Pressure distributions, Balance performance; Perceived satisfaction.	 No significant differences were found between the previous cushion and after using the prototype cushion for: transfer capacity indicated by FIM scores (p>0.05); MAS scores (p>0.05). Pressure distributions decreased significantly after using the prototype cushion (p=0.012). There were no statistical differences in balance performance using the prototype cushion (p>0.05). Participants reported higher perceived satisfaction with the prototype cushion in performing activities of daily living (p=0.006).
Hamanami et al. 2004 Japan Pre-Post N=36	Population: Mean age: 40.1 yr; Gender: males=28, females=8; Level of injury: paraplegia=36; Severity of injury: AIS A=35, B=1. Intervention: ROHO High Profile multi- cell air cushion. Outcome Measures: Tekscan pressure measurement system measuring total seat surface area, maximum pressure and area of high concentration.	 In all subjects, the highest pressure points were at the ischial areas. The maximum surface pressure was related to the ratio of high concentration areas to seating surface area at the point of minimum pressure (r=0.466, p=0.0042). A significant relationship between point of minimum pressure and maximum interface pressure or body weight was not found.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Gilsdorf et al. 1991 USA Post-Test N=17	Population: Paraplegia (N=6): Mean weight: 83 kg; Tetraplegia (N=5): Mean weight: 66 kg; Able-bodied controls (N=6): Mean weight: 76 kg. Intervention: 30 min sitting intervals, on different surfaces [Jay cushion; ROHO cushion; hard surface (controls only)] in a wheelchair that had a force plate attached to it. Outcome Measures: Normal and shear seating forces; Armrest forces; Centre of mass location.	 The cushion air pressure was significantly related to body weight (r=0.495, p=0.0021). On Jay cushion, those with tetraplegia had higher amplitude lateral movements and those with paraplegia had more lateral zero-crossings, when compared to ROHO cushion. Larger arm force variation was found among those with paraplegia. On the ROHO cushion, all subjects had larger normal and shear forces and an anterior centre of mass. Those with paraplegia had more variation, while those with tetraplegia had less, on static force factors between cushion types. SCI groups had higher force measurements than control group. Armrest forces applied by those with paraplegia were larger than those
Trewartha & Stiller 2011 Australia Case Series N=3	Population: Age range: 27-48 yr; Gender: males=3, females=0; Injury etiology: traumatic SCI=3; Level of injury: paraplegia=1, tetraplegia=2; Mean time since injury: 7.0 mo. Intervention: Xsensor pressure mapping system used to measure interface pressure of two cushions (Roho Quadtro Select HP versus Vicair Academy Adjuster) in two phases (both mapped daily x7 days and 3x/d for an additional 3 d with the cushion that demonstrated the lowest pressure in phase 1). Outcome Measures: Number of cells with pressure >100 mmHg, and 60-99 mmHg, compared between the two cushions.	 applied by those with tetraplegia (8-9% versus 5%, p<0.11). The number of cells with pressure >100 mmHg was consistently lower on the Roho Quadtro Select HP cushion compared to the Vicair Academy Adjuster cushion (p<0.001; 95% confidence interval 1.86 Vicair, 5.58 for Roho). There was variability across participants in the number of cells within the 60-99 mmHg range for each cushion type (no significant difference between the cushions; p=0.32).
Takechi & Tokuhiro 1998 Japan Case Series N=6	Population: Age range:18-48 yr; Gender: males=6, females=0; Level of injury: paraplegia=6; Severity of injury: complete=6. Intervention: Five different cushions (air cushion, contour cushion, polyurethane foam cushion, Cubicushion, silicone gel cushion). Outcome Measures: Tekscan BigMat pressure mapping system measuring peak pressures and area of total contact.	 If the area of contact was more widespread, the peak pressure was found to be lower. The air cushion had the largest area of pressure distribution and the lowest peak pressure (257-87g/cm²). The silicone cushion had the second lowest (292-129g/cm²) peak pressure.
Effects of o	different sitting surface loading on blood f	low and tissue displacement
Sonenblum & Sprigle. 2018b USA Pre-Post	Population: Age range= 18-40 yr; Gender: males=28, females=0; Level of injury: N/R; Time since injury >2 yr.	 Tissue compliance varied widely with on BMI being related to the amount of buttock tissue displacement (beta=0.229, 95% CI [0.106, 0.492)

Author Year Country Research Design Score Total Sample Size	Methods	Outcome	
Ninitial=34 Ninitial=28	Intervention: The seated buttock was unloaded, and loaded at lower (40–60 mmHg) and high (>200 mmHg) loads. Outcome Measures: Blood flow at the ischial tuberosity; tissue compliance using the Myotonometer measuring buttock tissue displacement at ischial tuberosity and ratio of displacment; risk factors of level fo injury, body mass index, blood pressure, smoking status, hematocrit, serum albumin, and lymphopenia.	 Ratio of displacement was associated with the smoking staus risk factor only (beta=0.070, 95% CI [0,018, 0.122] Blood flow was significantly reduced at high loads (p<0.05), while no significant changes were found at lower loads (p>0.05). Blood Ifow at lower loads differed according to having a history of pressure injuries, with those no history having a greater blood flow (mean(SD) - 1.5(0.7), p=0.006, 95%CI for difference =[0.2, 1.2] 	

Summarized Level 5 evidence studies:

The following level 5 evidence studies have been reviewed, and the overarching findings from the studies are highlighted in this section. As noted at the start of this chapter, these types of studies are not included in the discussion or in the conclusions.

Wu et al. (2016) provided participants with alternating pressure air cushions six times a week for two weeks, every three months for a total of 18 months. A high percentage of users were very satisfied with comfort and performance of these cushions. However, there were no measures of pressure or pressure ulcer incidences in relation to this trial therefore the full benefits of this type of cushion is not known.

Kovindha et al. (2015) surveyed chronic SCI wheelchair users in Thailand about their pressure ulcer prevalence, quality of life and health status. McClure et al. (2014) similarly surveyed a group of chronic SCI wheelchair users about their pressure ulcer prevalence and wheelchair cushion use. In both studies over half of the population had a pressure ulcer at some point. Common sites for current pressure ulcers were the IT, while that of healed pressure ulcers was the sacrococcygeal area. Kovindha et al. (2015), found those with current pressure ulcers were more depressed than those without current pressure ulcers. There was however no difference in health status between those with and without pressure ulcers. McClure et al. (2014) found that more than half of the participants used their wheelchair cushions when travelling in motor vehicles or airplanes.

Meaume et al. (2017) completed two observational studies exploring pressure ulcer incidence in recently spinal cord injured people who were at high risk for developing pressure injuries following a 35 day period of using a air-filled cushion; one study used a single compartment air-filled cushion (n=78) and the second using a multi compartment air-filled cushion (n=74). They found an incidence of 2.6% for developing a pressure injury in the single compartment air-filled cushion group versus a 4% rate in the other group. The authors indicate that this rate is low therefore recommended the use of these types of cushions however, they do not reference support for this being a low incidence rate. They also did not account for any other variables that may have supported good pressure management strategies to reduce the risk of devleopign pressure injuries given the participants were newly admitted and in a very supportive environment. Additionally, the authors also declare an affiliation and funding support with the manufacturer of the air-filled cushions.

Sprigle and Delaune (2014), and Sprigle (2010) investigated the properties of cushions used by SCI wheelchair users at an adult inpatient rehabilitation center. Cushion type varied from air, foam and fluid cushions. The average cushion age was approximately 30 months, and the

average cushion usage per day was 12 hours. The proportion of cushion damage from deformation, granulation, or stiffness to cushions was greater as cushions aged. Sumiya et al. 1997 reported similar findings with regards to frequency of replacement of cushions and types of cushions used.

Brienza et al (2018) explored the effects ot tissue compositions (fat and muscle) and deformation under the ischial tuberosities of 6 participants (4 with SCI, 2 without), on 6 different seat cushions using Magnetic Resonance Imaging (MRI) and Interface Pressure Mapping (IPM). They found that no one cushion performed best for all participants. They also found a difference in tissue composition between SCI and non-SCI participants. Participants with SCI having higher tissue volume reductions when loaded (sitting). Higher IPM Peak pressure indexes were also associated with lower overall tissue thicknesses in the ischial tuberosity areas. These findings reinforce that cushion selection must be individualized and the need for a comprehensive assessment to support the prescription of individualized seating equipment. Individual anatomy composition and cushion type will affect deformation response (and therefore assumed pressure injury response). The authors identify limitations in this study such as the small number of participants and that findings are observational. However, the findings are similar to other findings in this section and throughout the chapter as well as the Pressure Ulcer chapter.

Discussion

Sonenblum et al. (2018b) identified clinical factors for consideration that influence buttock tissue response to loading. The study found that people with higher BMI experienced greater magnitude of deformation of the ischial tuberosity tissue and slightly increased blood flow at lower loads. They also found that buttock tissue reached maximum deformation ("bottomed out") at a lower load for people who smoked compared to non-smokers. In regard to superficial blood flow, there was great variability across all participants, at both high (200+mmHg) and low loads (40-60mmHg). However, for people with a history of pressure injuries, there was a blood flow decrease even at low loads. These findings suggest that there are clinically related factors to consider during the process of determining the optimal seated surface for pressure management.

Crane et al. (2016) sought to measure the interface pressure characteristics of an offloading cushion (Ride Java in 3 configuration – full offloading, and addition of 2 well inserts) compared to an air inflation cushion (single valve ROHO). Their findings suggest that the offloading cushion provided improved pressure management than the air inflation, however since their isn't a universally accepted interface pressure parameter directly linked with pressure ulcer risk or development it is not known if these differences are enough to impact pressure ulcer incidence. Generalizability is also challenging due to limited information on participants, about their posture on the cushions and the small sample size.

Sonenblum et al. (2018a) also compared the Java in its offloading configuration with the 4" roho (single valve) as well as with the MatrixVi cushions. Their goal was to determine differences in tissue deformation using an MRI and Peak pressure index via IPM. The participants they chose had significant atrophied sitting surface tissue as this was felt to be one of the most challenging individuals to seat safely. Their findings suggest that there is a relationship between the tissue thickness under the iscial tuberosities and interface pressure, where the thinner the tissue the higher the pressures. However, they also found that all cushions deformed tissue in some

location, and that tissue responds individually to load in different locations, supporting the need for indivudalized assessment for identifying the optimal seat cushion for each person.

Vilchis-Aranguren et al. (2015) provided a wheelchair cushion personally customized to each participant's ischiogluteal area. After using these custom cushions for two months, pressure distributions around the ischiastic tuberosity zone decreased and participants reported increased satisfaction in performing activities of daily living compared to their regular cushions. These findings support the need for consideration of the sitting surface anatomy during the individualized assessment for seating.

The following studies evaluated different cushions using different interface pressure mapping systems and different pressure mapping outcomes. Typically, the studies used very small numbers of participants and did not evaluate a range of contributing factors such as posture on the cushions evaluated. Since there isn't an absolute pressure threshold identified related to pressure injury incidence, the findings from these studies provide data for consideration in clinical practice but should be used with clinical judgement for determining the optimal cushion in conjunction with the other seating componeents and configuration of the wheelchair frame. Trewartha and Stiller (2011) used pressure mapping to evaluate the Roho Quadtro and the Vicair Academy among three people with SCI. Findings indicated that the Roho Quadtro had significantly fewer cells in the greater than 100 mmHg range than the Vicair Academy but there was no significant difference in the 66-99mmHg range. The study did not examine the number of cells in the less than 65mmHg range. The location of the cells with greater than 100mmHg were not identified as being over bony prominences. Other pressure characteristics such as peak pressure gradient, area of distribution, or symmetry were not measured.

In the cushion comparison study by Gil-Agudo et al. (2009) the dual compartment air cushion exhibited the best mechanical performance with regard to the distribution of pressures and contact surface interface compared to the other three cushions studied (low profile air, high profile air, and gel and firm foam cushions). This study compared only four cushions, and based findigns only on distribution of pressure and not any of the other factors that are required for cushion selection. The main finding was that using interface pressure mapping could augment cushion selection but is only part of the cushion selection process.

Makhsous et al. (2007b), compared the contact sitting surface areas in two different conditions; one where the ischial support was partially removed for 10 mintues periods and the other where push up were performed every 20 minutes. The investigators found that the anterior portion of the seat cushion had a larger contact area among those with tetraplegia with higher pressure in the anterior and middle portion of the cushion for the partially removed ischial support condition. The authosr suggest that the reducing the contact area at the posterior sitting surface can be achieved with increased contact at the middle and anterior areas, thereby reducing the pressure over the sittign surface bony prominences.

Hamanami et al. (2004) used a pressure mapping system to evaluate the pressures found on an air floatation cushion (high profile ROHO) with 36 subjects with SCI. The results indicated that the optimal reduction in interface pressure was just before bottoming out on the cushion. No reliable method was found for systematically determining the appropriate air pressure for a ROHO for participants with SCI (Hamanami et al. 2004). Takechi and Tokuhiro (1998) also found that the air cushion had the lowest peak pressure and the highest area of pressure distribution followed by the silicone (gel) cushion.

In the study conducted by Burns and Betz (1999), three wheelchair cushions were tested: dry flotation (ROHO High Profile), gel (Jay 2), and dynamic (ErgoDynamic), the last consisting of two air-filled bladders (H-bladder, IT-bladder). These were compared to each other under high pressure conditions (upright sitting or IT-bladder inflated) and low-pressure conditions (seat tilted back 45° or H-bladder inflated). When analyzing the pressure placed on the IT, it was found that the pressure was higher during upright sitting than in the tilted back position for both the dry flotation and the gel cushion , with the dry flotation cushion providing more pressure redistribution than the gel cushion during upright sitting. Mean pressure with the IT-bladder-inflated cushion was greater than upright pressures for either the dry flotation or gel cushions.

Takechi and Tokuhiro (1998) studied the seated buttock pressure distribution in six patients with paraplegia using computerized pressure mapping. Five wheelchair cushions were evaluated (air cushion, contour cushion, polyurethane foam cushion, cubicushion, silicone gel cushion). Tests showed that if the area of contact was more widespread, the peak pressure was lower. The air cushion and the silicone cushion were found to have the lowest peak pressures.

Gilsdorf et al. (1991) studied subjects sitting on ROHO and Jay cushions. Normal force, shear force, centre of force, lateral weight shifts and amount of weight supported by armrests were studied under static and dynamic conditions. The ROHO cushion showed a tendency to carry a larger percentage of total body weight; have a more anterior centre of mass; and showed more forward shear force. There were more lateral weight shifts on the Jay cushion. Armrests supported a portion of body weight.

Seymour and Lacefield (1985) evaluated eight cushions for pressure, temperature effects and subjective factors influencing cushion purchase. While data indicated a wide variability in pressure measurements in individual subjects, the air-filled cushion (Bye Bye Decubiti) had the best pressure readings. The alternating pressure and foam cushions had consistently higher temperature readings across both groups.

Garber (1985) evaluated seven cushions based on amount of pressure reduction. The author also looked at how frequently each cushion was prescribed to subjects with quadriplegia and paraplegia. The ROHO cushion produced the greatest pressure reduction in the majority of subjects (51%) but was prescribed more often for subjects with quadriplegia versus paraplegia (55% versus 45%).

These studies demonstrate that there are individual variations in cushions needs inherent in those with SCI (e.g., paraplegia versus tetraplegia). Pressure mapping is a useful clinical tool to assist in determining pressure redistribution properties of cushions, but pressure is not the only factor to consider in cushion selection (Gil-Agudo et al. 2009). This is an important consideration as most of the studies reviewed have identified air inflation cushions as providing the lowest pressures but have not examined any other suitability factors. Objective findings together with the clinical knowledge of the prescriber, individual characteristics and the client's subjective reports need to be considered when prescribing a wheelchair cushion to minimize pressure ulcer prevention associated with a particular cushion type.

Conclusion

There is level 2 evidence (three randomized controlled trials; Gil-Agudo et al. 2009; Crane et al. 2016, Sonenblum et al. 2018a and from one pre-post study; Vilchis-Aranguren et al. 2015) suggesting that cushions that envelope specific to the individual's shape may have

lower sitting surface pressures may have higher patient satisfaction than cushions that envelope less.

There is level 2 evidence (from one prospective controlled trial Burns & Betz 1999 and one randomized control study, Sonenblum et al. 2018a and one cohort study, Makhsous et al. 2007) that cushions that reduce the pressure (e.g., dynamic versus static) or offload pressure in the ischial tuberosity region may be associated with potentially beneficial reduction in seating interface pressure and/or pressure injury risk factors.

There is level 4 evidence (one pre-post test study by Sonenblum et al. (2018b) to suggest that the factors of body mass index, smoking status and pressure injury history effect tissue response to different loads when seated on a cushion.

No one cushion is suitable for all individuals with SCI.

Cushion selection should be based on a combination of pressure mapping results, clinical knowledge of prescriber, individual characteristics, tissue loading response and preference.

More research is needed to see if decreasing ischial pressures or decreasing risk factors such as skin temperature via the use of specialty cushions will reduce pressure injury risk

Pressure mapping is a useful tool for comparing pressure redistribution characteristics of cushions for an individual, but it needs to be a part of the full evaluation not the main part or only evaluation; further research is needed to explore the relationship with tissue deformation.

5.5 Custom Contoured Cushion

Wheelchair users often sit for 12 to 16 hours per day resulting in unrelieved pressure over weight-bearing tissues that can result in tissue trauma and pressure sore development. Tissue trauma is a multidimensional process (Sprigle et al. 1990a; Brienza & Karg 1998). Two important risk factors that have been identified are externally applied pressure and tissue deformation. The following studies explore the use of custom contoured cushions (CCC) to improve pressure distribution and reduce tissue deformation (Sprigle et al. 1990b).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Li et al. 2014 China Prospective Controlled Trial N=32	Population: Non SCI group: Mean age: 35.2 yr. SCI group: Mean age: 38.3 yr; Level of injury: T7-L2. Intervention: Patients in each group compared a flat cushion (FC) to a new custom contoured cushion (CCC) created through a method that employs interface pressure measurements representing the buttocks and upper-thigh topology to machining the cushion directly. A new optimized algorithm of converting pressure distribution to the cutting depth according	 Subjective Evaluation: For SCI group, the CCC had high-pressure relief scores than the FC on LS (p<0.01), APS (p<0.005), and CD (p<0.01). For control group, the CCC had higher-pressure relief scores then those of FC on LS, APS and CD, (p<0.005) for all. Across both groups the CCC allowed form pressure redistribution

Table 21. Custom Contoured Cushions for SCI

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	to the load-deflection characteristics of the cushion foam. Outcome measures: Subjective evaluation of pressure relief and comfort on lateral stability (LS), Anteroposterior stability and comfort degree, Objective evaluation of maximum pressure (MP), Average Pressure (AP), Average pressure gradient (AVP), Balance coefficient (BC).	 and decreased interface pressure between the buttocks and cushion. Objective evaluation: 1. Using a Tekscan sensor for both Fc and CCC. Parameters were calculated through MP, AP, APG and BC that assess pressure distribution. 2. FC had increased pressure across all MP, AP, APG and BC. 3. CCC produced a lower MP and AP (p<0.01), as well as APG and BC (p<0.05) compared to FC which shows how CCC would prevent pressure sores in high-risk individuals.
Brienza & Karg 1998 USA Prospective Controlled Trial N=12	 Population: Age range: 21-52 yr; Gender: males=10, females=2; Level of injury: C4-5 to L1-2; BMI range: 17-32.3 kg/m². Intervention: Assessed forces for three different surfaces (flat foam, the initial contour and final optimized contour) with the force sensing array (FSA) pad between the cushion and buttocks. Compared SCI to seniors group. Outcome Measures: Electronic Shape Sensor, Computer Automated Seating System. 	 There was no difference in tissue stiffness between SCI and seniors group on any of the surfaces. There was a significant difference in pressure for the initial contour condition between SCI and seniors (p=0.027, p=0.017, respectively), but not within other conditions. The mean maximum depth was significantly deeper for the final contour as opposed to the initial contour (p<0.001). Also, the mean maximum depth was deeper in the SCI group than the seniors group within the final contour condition (p=0.016, p=0.053, respectively). Significant differences in interface pressure were found between flat and initial contour (p=0.023) and flat and final contour (p=0.006). No difference was found between the initial and final contour condition.
Sprigle et al. 1990b USA Pre-Post N=10	Population: Level of injury: paraplegia, tetraplegia, C4-5 to T12. Intervention: Personal wheelchair cushion and custom contour cushion (CCC), with two different foam stiffness (45 ILD, 55 ILD). Outcome Measures: Pressure distribution; eight Clinical variables: balance, posture, level transfer ability, comfort, propulsion, pressure relief/repositioning, spasticity/posture effect, skin reaction.	 CCC significantly lower pressure as compared to the subjects' usual cushion (p<0.05). Posture and balance were improved, without interfering with functional abilities, when using the CCC. CCC did not receive more than two negative responses regarding the eight variables.
Sprigle et al. 1990a USA Post-Test N=11	Population: Level of injury: paraplegia, tetraplegia, C5 – L3. Intervention: Two flat and two custom contour cushions (CCC) with two different foam stiffness (45 ILD, 55 ILD). (ILD Indentation Load Deflection)	 Pressure increased as the stiffness of the cushion increased (p<0.05). CCC had a significantly decreased pressure distribution (p<0.05), as compared to the flat cushion. CCC also had less soft tissue damage due to seat interface, less

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Outcome Measures: Pressure distribution – Oxford Pressure Monitor TM700; ILD test.	 harming effects of loading and increased deflation, as compared to the flat cushion. 4. Three important attributes to CCC found: increased enveloping; decreased foam compression; uniform pressure distribution.

Occurrences of pressure ulcers caused by prolonged sitting for persons with SCI are estimated to occur in 50% to 80 % of the SCI population (Brienza & Karg 1998). Current clinical practice for wheelchair cushion prescription is based on the perceived risk of a particular patient or patient group for developing pressure ulcers.

Li et al. (2014) in an unrandomized trial compared custom contoured cushions (CCC) to flat foam cushions for SCI wheelchair users and healthy prolonged sitting subjects, both groups were at high risk of pressure ulcer occurrence. CCC were designed to optimize interface pressure distribution. After using the cushions, both groups reported that CCC improved their lateral stability, anteroposterior stability and degree of comfort relative to flat cushions. Mean pressure, average pressure, average pressure gradient and balance coefficients, were all in favour of CCC compared to flat foam cushions, suggesting CCC are better at redistributing pressure

Sprigle et al. (1990a) conducted two studies to determine the use of CCC as a safe sitting surface. One study fabricated contoured foam cushions for 11 SCI subjects and compared mean pressures on two flat and two contoured foams with varying degrees of stiffness. Study results are in agreement with the Hertz theory that pressure increases with the stiffness of the material. Sitting on a CCC resulted in lower pressure distribution than sitting on flat foam. The force deflection curve of a thinner (one inch) cushion is lower than the force deflection curve of a thicker (three inch) cushion. Three important attributes of CCC were identified: increased enveloping provides more uniform pressure distribution and stable sitting surface and a decreased foam compression. CCC seat interface pressure is potentially less damaging to soft tissue as compared to flat cushions. Also, CCC have reduced damaging effects of external loading, reduced deflection and lower pressure distribution when compared to flat cushions.

Sprigle et al. (1990b) compared CCC to subjects' usual wheelchair cushions using pressure and clinical variables. CCC provided seating support at lower interface pressures. Use of CCC seemed to improve posture and balance without impeding the users' functional abilities. However, several disadvantages and cautions were identified with the use of CCC. Persons at high risk for pressure sores, or without the ability to complete pressure relief or repositioning, need to be fitted and monitored on initial use of CCC and trained in the ongoing use of CCC. Disadvantages identified with using CCC include; the user must be positioned in one location on the cushion, must recognize proper positioning within contour of cushion, and protect the foam from wetness and monitor foam fatigue over time.

Brienza and Karg (1998) had subjects sit on flat foam, initial contour or final contour cushions and measure the interface pressure using a pressure-sensing pad. Interface pressures were higher for the SCI group for all cushions tested. Pressure distributions for the SCI group are more sensitive to support surface characteristics (e.g., shape and compliance) than for the elderly group. Custom contouring foam cushions have positive effects on interface pressure as compared to flat foam cushions of the same density.

Conclusion

There is level 2 evidence (from two prospective controlled trials Brienza & Karg 1998; Li et al. 2014, one post-test study by ;; Sprigle et al. 1990a; and one pre-post test study by Sprigle et al. 1990b;) to support that custom contoured cushions (CCC) have attributes that redistribute interface pressure better in comparison to other foam and/or flat foam cushions. However, disadvantages and cautions are identified for the day to day use of CCC.

Contoured foam cushions compared to flat foam cushions seem to provide a seat interface that reduces the damaging effects of external loading and tissue damage.

5.6 Changes in Pressure during Static Sitting versus Dynamic Movement While Sitting

The following studies have explored the effects of dynamic movement on interface pressure. Stinson et al. (2013) examined changes during reaching as compared to static sitting while working at the computer. Tam et al. (2003) and Kernozek and Lewin (1998) both examined interface pressure differences between static and dynamic sitting.

able 22. Changes in a			
Author Year			
Country			
Research Design	Methods		Outcome
Score			
Total Sample Size			
Stinson et al. 2013 Ireland Pre-Post N=14	Population: Age range: 23-62 yr; Gender: males=12, females=2; Level of injury: paraplegia=8, tetraplegia=6; Chronicity range: 1-324 mo; able to safely lean forward and computer literate. Intervention: Investigate pressure relieving behaviours during everyday computer use. Strand A, (1 hr continuous computer use in standard position versus Strand B (reaching forward by 150° of arm length and typing for 5 min, alternated with 10 min of upright sitting). Outcome Measures: XSensor Interface pressure mapping system: [Dispersion Index (DI); Peak Pressure Index (PPI); Total Contact Area (CA)], Frequency of movement (left lean, right lean, push-up, other), Duration in changed position, Trunk angle and questionnaire.	 1. 2. 3. 	Only 4.9% of movements performed during normal computer use (Strand A) were considered pressure relief movements (they were considered "moderate" unloading - 51-75% reduction in interface pressure) Frequency and type of movement varied greatly (range 0-28 movements; median 5) 30% of which were classified as task related. 84.4% of movements yielded less than 25% reduction in interface pressure compared to normal sitting. During Strand B, DI and angle of trunk tilt were significantly reduced (p<0.05) compared to normal sitting, but it did not significantly affect CA. During Strand B, PPI for both the right and left ischial tuberosity (IT)

Table 22. Changes in Static and Dynamic Movement

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Population: Mean age: 45 yr; Level of injury: L3-T8; Time since injury range: 5-	 regions was significantly reduced (p<0.001), which represents an interface pressure reduction of ~52%. Questionnaire results indicated participants preferred to incorporate pressure management movements into regular activities (77%, n=10). The magnitude of dynamic average pressure under the ITs did not
Tam et al. 2003 China Prospective Controlled Trial N=20	34 yr. Intervention: 1) Comparison of interface pressure and IT location during static sitting and dynamic propulsion in standard wheelchair with no cushion; 2) Comparison between 'normal' group and test group; use of Quickie TNT manual wheelchair and a rigid seat pan; mathematical calculation of IT location. Outcome Measures: Peak pressure, Location of pressure optical motion analysis system.	 exceed the mean pressure recorded during static sitting. Peak pressures during static sitting were high with 4/10 people in the normal group and 7/10 in the SCI group reaching saturation pressures of 572 mmHg on the pressure mat. The ratio of minimum peak pressure to maximum peak pressure during dynamic propulsion was 1:4.1 in the normal group and 1:1.8 for the SCI group. No statistical difference between the normal and SCI groups in the location of the peak pressure over left and right ITs with the calculated locations of the ITs projected onto the pressure mat (20.7±11.5mm on left and 24.6±9.9mm on right for normal group and 17.7±13.1mm on left and 13.2±10.5mm on right for SCI group). Pelvic tilting angle (the angle between the pelvic plane and the reference seat plane which accounts for forward and backward rocking during propulsion), was statistically different between the normal and SCI groups (p<0.05, power=0.9); pelvic tilt angle was 11.2°±2.1° for the normal group.
Kernozek & Lewin 1998 USA Post Test N=15	Population: Gender: males=13, females=2; Mean weight=77.5 kg; Level of injury: paraplegia=15; Chronicity=chronic. Intervention: Wheelchair locomotion using static seating and dynamic seating. Outcome Measures: Novel Pliance pressure mapping system measuring peak pressure; pressure-time integral.	 Peak pressure was up to 42% higher within dynamic wheelchair locomotion when compared with static sitting. Static and dynamic seating peak pressure comparison was significant (t=5.4, p<0.025). No difference was found between static and dynamic seating pressure- time integral.

Tam et al. (2003) reported that sitting in a wheelchair has traditionally been considered to be static, however, wheelchair propulsion is recognized as dynamic. In this study pressure

mapping was used to determine the position of the IT during static and dynamic sitting (wheelchair propulsion). It was found that the IT were located 19.2±11.7 mm behind the peak pressure locations suggesting that rocking of the pelvis during wheelchair propulsion has a direct influence on the redistribution of loadings to the supporting tissues.

Kernozek and Lewin (1998) indicated that peak pressures during dynamic wheelchair propulsion were significantly higher than during static sitting by up to 42%. Pressure-time integral indicated that the cumulative effect of the loading was comparable between static and dynamic loading. Pressure-time integral between static dynamic trials was not significant. The author questions the impact dynamic movement has on skin health since peak pressures change throughout the locomotion cycle. The amount of IT travel during functional activities would also be an interesting factor to evaluate, as friction/shear may also have a significant impact on skin health for the wheelchair user.

Stinson et al. (2013) explored changes in interface pressure related to movement during normal computer use. 14 participants were asked to work at a computer for one hour, during which time changes in interface pressure and trunk position were noted as were frequency and duration of movements. Participants were then asked to reach forward (150% times their arm length) to type for five minutes and then return to normal upright sitting to type for 10 minutes, alternating these positions for a total period of 30 minutes. The same outcomes were measured. Results indicated that during regular computer use, frequency of movement varied greatly (range of 0-28 movements; an average of one movement every five minutes, with three participants not moving at all during the hour), with the majority of time spent in a normal upright position. Only 4.9% of the movements during Strand A produced a moderate reduction in interface pressure (51-75%), being ineffective for pressure redistribution. The questionnaire participants completed following the testing period, indicated that most felt they were completing effective pressure redistribution movements throughout the hour. The second part of this study which required participants to reach forward 150% times their arm length found a 52% decrease in interface pressure and a 24° change in trunk angle. Authors note that three of the 14 participants were unable to attain this position, with another three reporting that it was difficult or uncomfortable to attain this position. They also found a weak correlation between trunk angle and reduction in interface position and suggested that trunk angle should not be used as a predictor of the interface pressure unloading. Despite the small sample size, this study supports the incorporation of dynamic position changes within regular daily activities but also demonstrates that the effectiveness of the movement needs to be assessed to ensure adequate pressure redistribution.

Conclusion

There is level 4 evidence (from one post-test; Kernozek & Lewin 1998) to support that dynamic peak pressures are greater than static, but the cumulative loading is comparable between dynamic and static loading.

There is level 2 evidence (from one prospective controlled trial; Tam et al. 2003) to support that peak pressures are located slightly anterior to the ischial tuberosities (IT).

There is level 4 evidence (from one pre-post study; Stinson et al. 2013) to support the use and incorporation of forward reaching into daily activities as a means to promote pressure redistribution, provided the reach distance is adequate for an effective weight shift. Peak interface pressure is greater for dynamic movement in SCI subjects than static sitting but cumulative loading is comparable between dynamic and static loading for the SCI population.

Peak pressures appear to be located slightly anterior to the ischial tuberosities (IT).

The use and integration of forward reaching into daily life activities can be used as a means to promote regular pressure redistribution. Caution however is needed to ensure the movement is of adequate distance and duration to affect pressure management.

6.0 Position Changes for Managing Sitting Pressure/Postural Issues, Fatigue and Discomfort

Changing body positions frequently throughout the day to address discomfort, sitting pressures, fatigue and to adjust posture occur naturally and frequently. However, for people with a spinal cord injury, these position changes can be challenged by changes in their ability to physically move their own body as well as the need for increased frequency of position changes to address issues associated with prolonged sitting. The primary concern for people with spinal cord injury is the risk of pressure ulcer development resulting from increased pressure on the sitting surface and, decreased blood flow and tissue perfusion associated with prolonged sitting. Teaching individuals with spinal cord injuries to shift their weight regularly while seated is a common and intuitive recommendation for pressure injury prevention as it is hypothesized that this redistributes pressure on at risk tissues and allows for recovery of blood flow and oxygenation to these affected tissues (Bogie et al 1995; Consortium for Spinal Cord Medicine 2000; Coggrave & Rose 2003; Makhsous et al. 2007a). The studies outlined in Table 23 have examined the effect of amplitude, frequency and duration of position changes using outcome measures of interface pressure, blood flow, and tissue perfusion to determine the requirements to minimize risk. The studies have used these measures to examine the effects of intentional position changes including lateral leaning, forward leaning and vertical pushup and the use of positioning devices within the wheelchair frame including tilt, recline, tilt/recline combination and standing devices. As the studies in Table 23 have examined a variety of permutations of position changes with outcome measures, the table contains all studies related to position changes. The discussion section synthesizes the findings from each study as they apply to the primary position changes of leaning and push-ups, effects of wheelchair frame set-up, recline only, tilt only, and combinations of tilt, recline and standing.

Author Year Country PEDro Score Research Design Total Sample Size	Methods	Outcome		
	Leaning and Push-Up			
Hobson 1992 USA Prospective Controlled Trial N=22	Population: <i>SCI group:</i> Mean age:40.9 yr; Gender: males=10, females=2; Mean weight: 59.8 kg; Level of injury: paraplegia=7, tetraplegia=5; Severity of injury: complete=12; Mean time since injury: 19.5 yr; Chronicity=chronic; <i>Able</i> -	1. 2.	Mean maximum pressure was on average 26% higher in the SCI group versus the able-bodied group. Maximum reduction of TIS occurred with forward trunk flexion of 50° (-133%) and full body tilt of 20° (-85%). Backward	

Table 23. Changes in Interface Pressure, Blood Flow and Tissue Perfusion duringPosition Changes

	 bodied group: Mean age: 39.3 yr; Gender: males=6, females=4. Intervention: Comparison of Pressure mapping and shear measurements from midline neutral posture to eight typical wheelchair-sitting postures (trunk bending left and right, forward trunk flexion 30° and 50°, back recline 110° and 120° and body recline or tilt 10° and 20°). Outcome Measures: Tangentially induced shear measuring shear forces; Pressure distribution-Oxford Pressure Monitor Device measuring average and maximum pressure and peak pressures gradient. 	3. 4. 5.	recline to 120° caused increase in TIS of 25%. Forward trunk flexion reduced the average pressure for both groups; however, SCI group encountered a 10% increase in pressure at the initial 30° of forward flex before a reduction occurred. SCI subjects had a mean peak pressure gradient that was 1.5-2.5 greater than able-bodied subjects. Maximum decrease of pressure gradient from a neutral position happened after the backrest reclined to 120° (18%). When a sitting position change occurred, a similar shift to the anterior/posterior midline location of maximum pressure was experienced in both groups. From neutral, a forward trunk flexion at 30° and 50° produced a 2.4 and 2.7 cm posterior shift. When the backrest reclined to 120°, the greatest posterior shift occurred at 6 cm.
Makhsous et al. 2007a USA Case Control N=60	Population: <i>Paraplegia</i> (<i>n=20</i>): Mean age: 35.1 yr; Gender: males=20, females=0; Mean weight: 87.2 kg; Mean time since injury: 8.4 yr. <i>Tetraplegia</i> (<i>n=20</i>): Mean age: 36.5 yr; Gender: males=15, females=5; Mean weight: 81.8 kg; Mean time since injury: 9.2 yr; <i>Non-</i> <i>SCI</i> (<i>n=20</i>): Mean age: 39.3 yr; Gender: males=10, females=10; Mean weight: 71.3 kg. Intervention: 2-one hr sitting protocols: 1) Dynamic protocol: alternating every 10 min between normal sitting (sitting upright with full seat support and no added lumbar support) and an off-loading sitting (sitting upright with position in seat section tilted down 20° with pressure to IT and coccyx) configuration; 2) Wheelchair push-up every 20 min, while in normal sitting configuration. Outcome Measures: Transcutaneous partial pressure of oxygen (T _c PO ₂) and carbon dioxide (T _c PCO ₂).	1. 2. 3.	In normal sitting, mean T_cPO_2 at IT was <10mmHg and mean T_cPCO_2 was >60mmHg, for all groups. During off- loading sitting configuration, IT T_cPCO_2 was maintained >50mm Hg and T_cPCO_2 at<45 mm Hg for all groups. During push-up protocol (mean=49 sec), IT T_cPCO_2 increased and T_cPCO_2 reduced only slightly. With pressure release (off-loading configuration) average perfusion recovery time for T_cPCO_2 was 200-250 sec for all groups. T_cPO_2 perfusion recovery time was significantly shorter for control group than SCI groups, p<0.001.
Lin et al. 2014 USA Pre-Post N=23	 Population: Mean age: 46.0 yr; Gender: males=22, females=1; Injury etiology: SCI=16, multiple sclerosis=3, unilateral transfemoral amputation=1, bilateral transtibial amputations=3; Mean time since injury: 15.0 yr. Intervention: Participants performed repetitive weight-relief raises (WR) and shoulder external rotation (ER). Ultrasound imaging of the non-dominant shoulder in an unloaded baseline position and while holding a WR position before and after the WR/ER tasks. Outcome Measures: Acromiohumeral distance (AHD), Wheelchairs Users 	 1. 2. 3. 4. 5. 	There were no significant differences in the AHD before and after WR ($p=0.89$) and ER ($p=0.81$). The AHD in the pre-WR and pre-ER were significantly smaller than the AHD in the baseline shoulder neutral position ($p<0.001$). Participants with a narrower AHD at baseline had smaller shoulder circumferences ($p=0.044$). Participants with increased years of disability had greater AHD percentage narrowing after the WR task ($p=0.008$). More shoulder pain on WUSPI had a greater percentage narrowing after the ER task ($p=0.007$).

	Chaulder Dein Index (M/LICDI) OMNI	6	Destining to with higher secret on the
	pain scale (OMNI).	6.	Participants with higher scores on the OMNI after ER had greater percentage narrowing of AHD after ER (p=0.003).
Wu & Bogie 2014 USA Pre-Post N=13	Population: Mean age: 42 yr; Gender: males=10, females=3; Level of injury: C2-T12; Mean time since injury: 8 yr. Intervention: Participants were provided with alternating-pressure air cushion (APAC) to compare with their own independent pressure relief (IPR) methods. Outcomes were assessed at baseline and every 3 mo over an 18 mo period. Outcome Measures: Transcutaneous oxygen tension (TcPO ₂), blood flow components (cardiac, respiratory, neurogenic) and ischial interface pressure (IP).	 1. 2. 3. 4. 5. 6. 	IPR significantly decreased IP (p<0.05), and significantly increased T _C PO ₂ (p<0.05) from baseline to post- assessment. The cardiac component of blood flow increased significantly (p<0.05) using IPR post-intervention. APACs significantly decreased IP (p<0.05) from baseline to post- assessment. There was no significant difference between using IPR or APACs in T _C PO ₂ post-assessment. APACs produced significantly higher neurogenic (p<0.05) and respiratory (p<0.01) components post-assessment. Following APAC use, the cardiac component of blood flow was significantly lower (p<0.001).
Sonenblum et al. 2014 USA Pre-Post N=17	Population: Median age: 45.0 yr; Gender: males=3, females=14; Level of injury: cervical=3, thoracic=12, lumbar=1, unknown=1; Level of severity: complete=8, incomplete=8, unknown=1; Median time since injury: 7 yr. Intervention: Participants received a randomized order of three forward leans (small, intermediate and full) and two sideward leans (intermediate and full) while seated on each of three different wheelchair cushions (Matrix Vi, Jay J2, and ROHO). Leans were maintained for one minute, with 8 min of erect sitting in between different leans. Outcome Measures: Ischial interface pressure (IP), Blood flow.	 1. 2. 3. 4. 5. 6. 7. 	All leans except for the small forward lean significantly reduced IP (p<0.001). The full frontward and sideward leans significantly reduced IP more than all other leans (p<0.001), but were not significantly different from each other (p=0.12). Across all leans, IP was significantly higher when participants were sitting on the Matrix Vi compared to the other two cushions (p<0.001). The Jay J2 and ROHO cushions had no significant differences between them (p=0.90). The ROHO cushion had the lowest IP value in erect sitting (p<0.001). Blood flow during erect sitting and small forward leans was significantly lower than blood flow during the full and intermediate leans in both forward and sideward directions (p<0.001). There was no significant effect of cushion (p=0.89) or cushion and posture (p=0.67) on blood flow.
Smit et al. 2013 Netherlands Pre-Post N=12	Population: Mean age: 38.1 yr; Gender: males=12, females=0; Level of injury: paraplegia=3; tetraplegia=9; Level of severity: AIS A=9, B=3; Mean BMI: 82.2 kg; Mean time since injury: 173 mo; Cushion type: air cushions=10, gel=2. Intervention: Participants using their own wheelchairs and cushions were asked to perform a series of pressure relief movements in order: bending forward, leaning sideways to right and push up, for as long as possible to a maximum of 2 min. A 30 sec rest to gain baseline values, occurred before each test and then a 30 min rest after the movement.	2.	Interface Pressure: Compared to rest, IT pressure was significantly lower during all movements; push-ups=19±44 mmHg (p<0.001), bending forward 56±33 mmHg (p<0.001), leaning sideways=44±38mmHg (p<0.001). Electrical stimulation of gluteal and hamstring muscle reduced IT pressure (p=0.003); no significant differences between ES condition and Pressure relief movements. Oxygenation: Data from only nine participants was reliable due to technical issues with testing equipment. Compared to rest, significant increase in mean oxygenation for bending forward

	Outcome Measures: Interface pressure mapping to gather mean pressure values under both ITs (defined as the 3x3 sensors under each IT). Oxygenation data was obtained using a rigid probe attached to the left IT, to measure oxygen saturation of hemoglobin, and velocity of blood flow captured as mean and peak blood flow. Electrical stimulation with two surface probes at the upper part of the gluteal muscle above the sitting area and one halfway of the hamstring area with stimulation increasing in increments of 5- 10 mA to a maximum without discomfort or excessive muscle contraction	3.	(p=0.01), leaning sideways (p=0.01), and push up (p=0.01). No significant differences in mean oxygenation for electrical stimulation (p=0.57). No significant difference was found between pressure relief movements. Significant correlation between oxygenation and electrical stimulation (r=0.7), but not for oxygenation change and mean IT pressure. Blood flow: Compared to rest, significant increase in blood flow for bending forward (p=0.02), leaning sideways (p=0.03) and push-up (p=0.02). No significant change in mean blood flow
	disrupting normal sitting (mean=87±18.5 m). Blood flow, oxygenation and IT pressure were compared during all test conditions.		with electrical stimulation ($p=0.75$). There was a significant difference in peak blood flow for electrical stimulation ($p=0.007$) and bending forward ($p=0.006$) compared to rest.
Henderson et al. 1994 USA Pre-Post N=10	Population: Mean age: 33.5 yr; Gender: males=9, females=1; Level of injury: paraplegia=7, tetraplegia=3; Mean weight: 77.7 kg; Time since injury range: 1 mo-7 yr. Intervention: Three different postures: 35° tilt backward, 65° tip/ tilt backward, 45° lean forward. Outcome Measures: Pressure distribution- Tekscan F-Scan System measuring the average of maximum pressure at the ITs and an average of the area around the ITs.	1. 2. 3.	There was no significant decrease in pressure at a 35° tilt. A significant decrease occurred in maximum point pressure (100mmHg) and circumscribed area pressure (71mmHg) at a 65° tip/tilt (p<0.05). The greatest decrease in pressure occurred when leaning 45° forward. When leaning forward, a 70% decrease in area pressure (33mmHg) and a 78% decrease in maximum pressure (34mmHg) were experienced (p<0.05).
Coggrave & Rose 2003 UK Case Series N=50	Population: Age Range: 20-83 yr; Gender: males=33, females=13; Injury etiology: SCI=50; Severity of injury: Frankel grade A-D; Time since injury range: 5 wk-50 yr. Intervention: Retrospective chart review. Outcome Measures: Effect of pressure relief on transcutaneous oxygen tension (TCPO2).	1. 2. 3.	Mean duration of pressure relief required to raise tissue oxygen to unloaded levels was 1 min 51 sec (range 42 sec-3½ min). Leaning forward with elbows or chest on knees, leaning from side to side or tipping/tilting the wheelchair back to >65° were all effective for pressure relief (raising TCPO2 to unloaded levels) and more easily sustained for most individuals than a pressure relief lift. Resulted in a change in practice at the seating clinic.
	Effects of Wheelchair Frame S	Set-l	Jp
Makhsous et al. 2007b USA Case Control N=60	Population: Mean age:37 yr; Gender: males=45, females=15; Level of injury: paraplegia=20, tetraplegia=20, able- bodied=20. Intervention: Two 1-hr protocols. 1) Alternative protocol-sitting position was altered every 10 min between normal and WO-BPS (partially removed support at ischial area). 2) Normal protocol- normal posture and push-ups or Hoyer lifts every 20 min. Outcome Measures: XSensor pressure mapping system measuring Interface	1. 2. 3. 4.	Those with tetraplegia had a larger contact area at the anterior portion of the cushion, as compared to the other groups. The mean pressure over the whole cushion was significantly different for each group (p<0.001). Those with tetraplegia had the highest mean pressure during the WO-BPS posture, as compared to the other groups (p<0.001). The contact area of the posterior portion of the cushion and the peak interface
	pressure measures of total contact area, average pressure and peak pressure on		pressure decreased in all groups, with the largest decrease in those with

	backrest and anterior middle and posterior sections of the seat.	5. 6.	tetraplegia for the latter. The mean pressure of the anterior and middle portions of the cushion increased in all groups. At the posterior portion of the seat where ischial tuberosities are usually positioned, average pressure was higher for those with paraplegia (88.9 mmHg). Average push up time was 49 sec for those with paraplegia.
Maurer & Sprigle 2004 USA Pre-Post N=14	Population: Mean age: 37 yr; Gender: males=9, females=5; Level of injury: paraplegia=14; Chronicity: chronic. Intervention: Seat angle decrease at 0, 2, 3, 4 inches. Outcome Measures: Force Sensing Array pressure mapping system measuring Total force, Contact area, Peak pressure index, Dispersion index, Seat pressure index.	1. 2. 3. 4. 5.	Total force increased with decreasing seat angle from 751.5 N (baseline) to 774.5 N (4 in). Contact area varied as the seat dropped (p=0.03). Contact area was highest at baseline and after a 2 in decrease. No differences in peak pressure occurred. As the seat dropped, less pressure was concentrated under the ischial tuberosities (p<0.001).The dispersion index was higher at baseline than when seat decreased. Seat pressure index was higher at baseline than when seat decreased (p=0.008).
Position Change: Recline Only			
Hobson 1992 USA Prospective Controlled Trial N=22	 Population: SCl group: Mean age: 40.9 yr; Gender: males=10, females=2; Mean weight: 59.8 kg; Level of injury: paraplegia=7, tetraplegia=5; Severity of injury: complete=12; Mean time since injury: 19.5 yr; Chronicity: chronic. Able- bodied group: Mean age: 39.3 yr; Gender: males=6, females=4. Intervention: Comparison of Pressure mapping and shear measurements from midline neutral posture to eight typical wheelchair-sitting postures (trunk bending left and right, forward trunk flexion 30° and 50°, back recline 110° and 120° and body recline or tilt 10° and 20°). Outcome Measures: Tangentially induced shear measuring shear forces; Pressure distribution-Oxford Pressure Monitor Device measuring average and maximum pressure and peak pressures gradient. 	1. 2. 3. 4. 5.	Mean maximum pressure was on average 26% higher in the SCI group versus the able-bodied group. Maximum reduction of TIS occurred with forward trunk flexion of 50° (-133%) and full body tilt of 20° (-85%). Backward recline to 120° caused increase in TIS of 25%. Forward trunk flexion reduced the average pressure for both groups; however, SCI group encountered a 10% increase in pressure at the initial 30° of forward flex before a reduction occurred. SCI subjects had a mean peak pressure gradient that was 1.5-2.5 greater than able-bodied subjects. Maximum decrease of pressure gradient from a neutral position happened after the backrest reclined to 120° (18%). When a sitting position change occurred, a similar shift to the anterior/posterior midline location of maximum pressure was experienced in both groups. From neutral, a forward trunk flexion at 30° and 50° produced a 2.4 and 2.7cm posterior shift. When the backrest reclined to 120°, the greatest posterior shift occurred at 6cm.
Position Change: Tilt Only			
Sonenblum & Sprigle 2011c USA RCT Crossover PEDro=4 N=11	Population: Mean age: 45.5 yr; Gender: males=9, females=2; Level of injury: incomplete=6, complete=5; Chronicity: sub-acute, chronic; Mean weight: 80 kg; Mean duration of w/c use: 9.4 yr. Intervention: A randomization of four tilt	1. 2.	Small tilts (15°) resulted in a significant increase in blood flow (p=0.016); magnitude was small and highly varied. An increase in blood flow at 15° did not correspond with a decrease in loading
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	sequences in 15° increments, separated by 5 min reperfusion periods. Outcome Measures: Blood flow, Interface pressure.	3. 4. 5. 6. 7.	when compared to upright (peak p=0.085, mean pressure p=0.131). 15° tilt from upright resulted in significant increase in blood flow with no significant decrease in pressure. Peak and mean pressures at 30° were significantly different than at preceding 15° tilt (p<0.001); blood flow did not increase further (p=0.118). There were no statistical differences in pressure and flow in upright-to-30° tilts compared to 15° to 30° tilts. Pressure reduction required tilts >30°; blood flow increased with all tilts beyond upright but no further increase when going from 15° to 30°. Most participants (9/11) required maximum tilt (45°-60°) to increase blood flow >/=10%.
Hobson 1992 USA Prospective Controlled Trial N=22	 Population: <i>SCI group:</i> Mean age: 40.9 yr; Gender: males=10, females=2; Mean weight: 59.8 kg; Level of injury: paraplegia=7, tetraplegia=5; Severity of injury: complete=12; Mean time since injury: 19.5 yr; Chronicity: chronic; <i>Ablebodied group:</i> Mean age: 39.3 yr; Gender: males=6, females=4. Intervention: Comparison of Pressure mapping and shear measurements from midline neutral posture to eight typical wheelchair-sitting postures (trunk bending left and right, forward trunk flexion 30° and 50°, back recline 110° and 120° and body recline or tilt 10° and 20°). Outcome Measures: Tangentially induced shear measuring shear forces, Pressure distribution-Oxford Pressure Monitor Device measuring average and maximum pressure and peak pressures gradient. 	1. 2. 3. 4.	Mean maximum pressure was on average 26% higher in the SCI group versus the able-bodied group. Maximum reduction of TIS occurred with forward trunk flexion of 50° (-133%) and full body tilt of 20° (-85%). Backward recline to 120° caused increase in TIS of 25%. Forward trunk flexion reduced the average pressure for both groups; however, SCI group encountered a 10% increase in pressure at the initial 30° of forward flex before a reduction occurred. SCI subjects had a mean peak pressure gradient that was 1.5-2.5 greater than able-bodied subjects. Maximum decrease of pressure gradient from a neutral position happened after the backrest reclined to 120° (18%). When a sitting position change occurred, a similar shift to the anterior/posterior midline location of maximum pressure was experienced in both groups. From neutral, a forward trunk flexion at 30° and 50° produced a 2.4 and 2.7cm posterior shift. When the backrest reclined to 120°, the greatest posterior shift occurred at 6cm.
Giesbrecht et al. 2011 Canada Pre-Post N=18	 Population: Mean age: 42.6 yr; Gender: males=17, females=1; Level of injury: tetraplegia=10, paraplegia=8; Mean time since injury: 18.2 yr; Mean weight: 74.7 kg; Mean BMI=24.1 kg/m². Intervention: Forced Sensing Array (FSA) interface pressure mapping system, 6 min settling period; test wheelchair-Quickie Iris with Jay 2 cushion, seat to back angle set at 100°, sitting pressure at tilt angles measured at 10° increments to a maximum of 50°. Outcome Measures: Peak pressure index readings on the ischial tuberosities and sacrum. 	1. 2. 3. 4.	No statistically significant difference in pressure between right and left ischial tuberosities (IT) at each angle of tilt. No significant reduction in IT IP at 10° tilt compared to baseline; modestly significant change at 20° (right, p=0.034; left, p=0.001); all other angles showed highly significant change (p=0.000) compared to baseline. No significant differences between those with paraplegia versus tetraplegia. Mean sacral IP did not change significant reduction at 30° (p=0.002), 40° (p=0.000) and 50° (p=0.000).

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		5.	Compared to paraplegia group, mean sacral pressure values were significantly
			(p=0.036), 10° (p=0.025), 30° (p=0.044) and approached significance at 20°
			(0.067).
	Population: Mean age: 37.7 yr; Gender:	1.	Body tilt had a significant effect on the
Spiikerman et al. 1995	males=15, females=3; Level of injury: C2-		mean pressure, p=0.003.
Netherlands	L2; Severity of injury: complete=18.	2.	At seat inclination of 5°, 15° and 25°,
Pre-Post	Intervention: Interface pressure was		overall mean pressure was 86.79, 86.90
N=18	assessed on SCI patients using various		and 82.91, respectively.
	seat inclinations.		
	Outcome Measures: Mean pressure.		
	Population: Mean age: 33.5 yr; Gender:	1.	There was no significant decrease in
	males=9, females=1; Mean weight: 77.7	~	pressure at a 35° tilt.
	kg; Level of injury: paraplegia=/,	2.	A significant decrease occurred in
	tetraplegia=3; Time since injury range: 1		maximum point pressure (100mmHg)
Henderson et al. 1994	mo-7 yr.		and circumscribed area pressure
USA	Intervention: Inree different postures:	~	(71mmHg) at a 65° tip/tilt (p<0.05).
Pre-Post	35° tilt backward, 65° tip/ tilt backward,	3.	I ne greatest decrease in pressure
N=10	45° lean forward.		occurred when leaning 45° forward.
	distribution Takagen F. Osen Quatern		when leaning forward, a 70% decrease
	distribution- Tekscan F-Scan System		In area pressure (33mmHg) and a 78%
	measuring the average of maximum		decrease in maximum pressure
	pressure at the ITs and an average of the		(34mmHg) were experienced (p<0.05).
	Bosition Change: Combinations of Tilt	Pooliu	a and Stand
	Position Change. Combinations of Titl, F		Muselo porfusion significantly increased
	ropulation. Mean age. so yr, Genuer.	1.	from baseling to both 25° tilt and 120°
	C4 T5: Moon PMI: 24 5:22 kg/m ²		realize and 25° tilt and 120° (p $_{\circ}0.05)$)
	Intervention: Participants used the		other test positions did not show
	same study power wheelchair with tilt		significant differences
	and recline and high density contoured	2	Normalized skin perfusion showed
	form cushion. All participants completed	۷.	significant increase $(n < 0.05)$ from
	a protocol of: baseline-5 min in 0° tilt and		baseline to 35° tilt and 100° recline and
	recline (sitting induced ischemia period):		all tilt angles and 120° recline: other test
	5 min one of six randomly assigned test:		positions did not show significant
	5 min in washout period (35° tilt and		differences
	120° recline). The tilt and recline	3.	Normalized skin perfusion in 120°
Jan et al. 2013a	120° recline). The tilt and recline positions were randomly assigned (15°,	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed
Jan et al. 2013a USA	120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120°	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle
Jan et al. 2013a USA RCT Crossover	120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline).	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions
Jan et al. 2013a USA RCT Crossover PEDro=4	120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20	120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20	 120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; 	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p <0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20	 120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to 	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p <0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20	120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to measure muscle tissue oxygen	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20	120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to measure muscle tissue oxygen saturation (muscle perfusion) to a depth	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20	120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to measure muscle tissue oxygen saturation (muscle perfusion) to a depth of 0-14 mm on right IT. Muscle and skin	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20	120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to measure muscle tissue oxygen saturation (muscle perfusion) to a depth of 0-14 mm on right IT. Muscle and skin perfusion during the tilt/reclined position	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20	120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to measure muscle tissue oxygen saturation (muscle perfusion) to a depth of 0-14 mm on right IT. Muscle and skin perfusion during the tilt/reclined position was normalized to skin perfusion in	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20	120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to measure muscle tissue oxygen saturation (muscle perfusion) to a depth of 0-14 mm on right IT. Muscle and skin perfusion during the tilt/reclined position was normalized to skin perfusion in upright sitting.	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20	120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to measure muscle tissue oxygen saturation (muscle perfusion) to a depth of 0-14 mm on right IT. Muscle and skin perfusion during the tilt/reclined position was normalized to skin perfusion in upright sitting. Population: Mean age: 38 yr; Gender:	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20	 120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to measure muscle tissue oxygen saturation (muscle perfusion) to a depth of 0-14 mm on right IT. Muscle and skin perfusion during the tilt/reclined position was normalized to skin perfusion in upright sitting. Population: Mean age: 38 yr; Gender: males=8, females=1; Level of injury: C4-Text of the state of the	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20 Jan et al. 2013b	120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to measure muscle tissue oxygen saturation (muscle perfusion) to a depth of 0-14 mm on right IT. Muscle and skin perfusion during the tilt/reclined position was normalized to skin perfusion in upright sitting. Population: Mean age: 38 yr; Gender: males=8, females=1; Level of injury: C4- T5; AIS A=1, B=1, C=7; Mean BMI=24.5	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20 Jan et al. 2013b USA	120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to measure muscle tissue oxygen saturation (muscle perfusion) to a depth of 0-14 mm on right IT. Muscle and skin perfusion during the tilt/reclined position was normalized to skin perfusion in upright sitting. Population: Mean age: 38 yr; Gender: males=8, females=1; Level of injury: C4- T5; AIS A=1, B=1, C=7; Mean BMI=24.5 kg.m ² ; Mean time since injury: 6 yr.	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20 Jan et al. 2013b USA PEDro=5	120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to measure muscle tissue oxygen saturation (muscle perfusion) to a depth of 0-14 mm on right IT. Muscle and skin perfusion during the tilt/reclined position was normalized to skin perfusion in upright sitting. Population: Mean age: 38 yr; Gender: males=8, females=1; Level of injury: C4- T5; AIS A=1, B=1, C=7; Mean BMI=24.5 kg.m ² ; Mean time since injury: 6 yr. Intervention: Participants used the	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20 Jan et al. 2013b USA PEDro=5 RCT Crossover	 120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to measure muscle tissue oxygen saturation (muscle perfusion) to a depth of 0-14 mm on right IT. Muscle and skin perfusion during the tilt/reclined position was normalized to skin perfusion in upright sitting. Population: Mean age: 38 yr; Gender: males=8, females=1; Level of injury: C4-T5; AIS A=1, B=1, C=7; Mean BMI=24.5 kg.m²; Mean time since injury: 6 yr. Intervention: Participants used the same study power wheelchair with tilt and radius and publics and heals. 	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20 Jan et al. 2013b USA PEDro=5 RCT Crossover N=9	 120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to measure muscle tissue oxygen saturation (muscle perfusion) to a depth of 0-14 mm on right IT. Muscle and skin perfusion during the tilt/reclined position was normalized to skin perfusion in upright sitting. Population: Mean age: 38 yr; Gender: males=8, females=1; Level of injury: C4-T5; AIS A=1, B=1, C=7; Mean BMI=24.5 kg.m²; Mean time since injury: 6 yr. Intervention: Participants used the same study power wheelchair with tilt and recline and cushion and back support. All participants accepted completed completed	3.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20 Jan et al. 2013b USA PEDro=5 RCT Crossover N=9	 120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to measure muscle tissue oxygen saturation (muscle perfusion) to a depth of 0-14 mm on right IT. Muscle and skin perfusion during the tilt/reclined position was normalized to skin perfusion in upright sitting. Population: Mean age: 38 yr; Gender: males=8, females=1; Level of injury: C4-T5; AIS A=1, B=1, C=7; Mean BMI=24.5 kg.m²; Mean time since injury: 6 yr. Intervention: Participants used the same study power wheelchair with tilt and recline and cushion and back support. All participants completed a protection of the same study power of 45 min in 0 titte 	3. 1. 2.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between muscle and skin perfusion.
Jan et al. 2013a USA RCT Crossover PEDro=4 N=20 Jan et al. 2013b USA PEDro=5 RCT Crossover N=9	 120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the left ischial tuberosity; Near-infrared Spectroscopy used to measure muscle tissue oxygen saturation (muscle perfusion) to a depth of 0-14 mm on right IT. Muscle and skin perfusion during the tilt/reclined position was normalized to skin perfusion in upright sitting. Population: Mean age: 38 yr; Gender: males=8, females=1; Level of injury: C4-T5; AIS A=1, B=1, C=7; Mean BMI=24.5 kg.m²; Mean time since injury: 6 yr. Intervention: Participants used the same study power wheelchair with tilt and recline and cushion and back support. All participants completed a protocol of: baseline of 15 min in 0 tilt and recline (sitting induced inchemic) 	3. 1. 2.	Normalized skin perfusion in 120° recline with all three tilt angles, showed significant increase compared to muscle perfusion in these test positions (p<0.05); other combinations did not show a significant difference between muscle and skin perfusion.

	period), followed by the testing period, a second ischemia period and then 15 min recovery period (35° tilt and 120° recline). The test positions were randomly assigned; 3 min in 35° tilt and 120° recline, 1 min in same tilt-recline and 0 min in tilt and recline. Outcome Measures: Laser Doppler Flowmetry used to measure mean and peak skin perfusion over the right ischial tuberosity. Normalized individual skin perfusion response to baseline sitting skin perfusion.	3. 4. 5.	significantly higher than the 0 min duration (1.57 \pm 0.21). Normalized mean skin perfusion was not significantly different between the 1 min and 0 min durations. The peak skin perfusion of the reactive hyperemic response did not show significant difference for any test protocol while peak skin perfusion was higher the 3 (4.1 \pm 1.1) and 0 (3.7 \pm 1.5) min durations but not in the 1 min protocol (2.15 \pm 0.15). During the second ischemic sitting period, significantly higher normalized skin perfusion occurred at the 3 min (1.15 \pm 1.5) compared to the 1 min (0.96 \pm 0.06; p<0.017) and compared to the 0 min (0.98 \pm 0.03; p<0.017).
Jan & Crane 2013c USA RCT Crossover PEDro=4 N=11	Population: Mean age: 37.7 yr; Gender: males=9, females=2; Mean BMI: 24.7±2.6 kg/m ² ; Level of injury: AIS A=4, B=2, C=5. Intervention: Participants all used the same study power wheelchair with tilt and recline and back support. All participants completed a protocol of: baseline - 5 min in 0° tilt and recline (sitting induced ischemia period); 5 min 1 of 6 randomly assigned test; 5 min in washout period (35° tilt and 120° recline). The tilt and recline positions were randomly assigned (15°, 25° and 35° tilt each with 100° and 120° recline). Outcome Measures: Laser Doppler Flowmetry used to measure skin perfusion over the right ischial tuberosity and sacrum (midpoint between the PSIS and adjacent vertebrae spinous process).	1.	Sacral skin perfusion did not show a significant difference in the six test positions (p>0.05). Skin perfusion at the ischial tuberosity showed significant increase at all tilt positions combined with 120° recline (p<0.01) and 35° tilt with 100° recline (p<0.008).
Sonenblum & Sprigle 2011c USA RCT Crossover PEDro=4 N=11	Population: Mean age: 45.5 yr; Gender: males=9, females=2; Level of injury: incomplete=6, complete=5; Chronicity: sub-acute, chronic; Mean weight: 80 kg; Mean duration of w/c use: 9.4 yr. Intervention: A randomization of four tilt sequences in 15° increments, separated by 5 min reperfusion periods. Outcome Measures: Blood flow, Interface pressure.	 1. 2. 3. 4. 5. 6. 	Small tilts (15°) resulted in a significant increase in blood flow (p=0.016); magnitude was small and highly varied. An increase in blood flow at 15° did not correspond with a decrease in loading when compared to upright (peak p=0.085, mean pressure p=0.131). 15° tilt from upright resulted in significant increase in blood flow with no significant decrease in pressure. Peak and mean pressures at 30° were significantly different than at preceding 15° tilt (p<0.001); blood flow did not increase further (p=0.118). There were no statistical differences in pressure and flow in upright-to-30° tilts compared to 15° to 30° tilts. Pressure reduction required tilts >30°; blood flow increased with all tilts beyond upright but no further increase when going from 15° - 30°.

		7.	Most participants (9/11) required maximum tilt (45°-60°) to increase blood flow ≥10%.
	Population: Mean age: 37.7 yr; Gender:	Tilt-i	n-Space Angle Effect:
Jan et al. 2010 USA RCT Crossover PEDro=4 N=11	traumatic SCI=11; Level of severity: AIS A=4, B=2, C/D=5; Mean time since injury: 8.1 yr; Mean BMI: 24.7 kg/m ² . Intervention: All participants completed six protocols randomly assigned (15°, 25°, 35°, each with 100° and 120° recline; 5 min sitting-induced ischemic period (no tilt/recline) followed by 5 min wheelchair tilt and recline pressure- relieving period; 5 min washout period between each test position. Outcome Measures: Laser Doppler	1. 2.	Combined with 100° recline, tilt at 35° resulted in a significant increase in skin perfusion ($p<0.05$) as compared to upright; no significant increase occurred at 15° and 25°. Combined with 120° recline, all tilt angles (15°, 25°, 35°) showed a significant increase in skin perfusion compared to upright sitting ($p<0.05$) and 35° resulted in significant increase compared with 15° tilt ($p<0.05$).
	Flowmetry used to measure skin perfusion over the ischial tuberosity and normalized to skin perfusion in upright sitting.	Rec 1. 2.	line Angle Effect: Combined with 15° tilt, 120° recline did not induce a significant increase in skin perfusion compared with 100° recline. Combined with 25° tilt or 35° tilt, 120° recline induced a significant increase in skin perfusion compared to 100° recline (p<0.05 for both tilt angles).
Sprigle et al. 2010 USA RCT PEDro=4 N=16	 Population: Mean age: 36.9 yr; Injury etiology: SCI=16; C4-T12 (AIS A to D); Level of injury: paraplegia, tetraplegia; Mean time since injury: 12.9yr ± 14.5mo). Intervention: Randomization of five different angles of tilt, recline, and stand positions performed for 1 min each. Outcome Measures: Normalized seat and backrest forces (% of max load) Rate of loading change. 	 1. 2. 3. 4. 5. 6. 	Normalized seat loads were linearly related to angles of tilt, recline and standing (increase angle, decrease % maximum load). Full stand (75° seat angle) and recline (90° backrest angle) resulted in greater unloading than full tilt (55° seat angle). Maximum unloading occurred in full stand and recline. Rate of change in force was different for each. configuration (p=0.000); loads decreased on the seat with increasing amounts of tilt, recline and standing; rate of increased loading on the backrest was higher with tilt than recline; standing was the only configuration that decreased load off seat and backrest simultaneously. Reduced seat load is greater with full recline and full stand (61%) versus full tilt (46%). There is no threshold point for drop in load (linear relationship), therefore, an "effective" tilt, recline or stand angle cannot be defined.
Inskip et al. 2017 USA Prospective Controlled Trial N=29	Population: Autonomically-incomplete SCI (n=12): Mean age= 42.6 yr; Gender: males=6, females=6; Level of injury: C1- T12; Mean time since injury= 18.9 yr. Autonomically-complete SCI (n=7): Mean age= 37.0 yr; Gender: males=5, females=2; Level of injury: C1-T12; Mean time since injury= 16.6 yr. Healthy Controls (n=10): Mean age= 31.9 yr; Gender: males=6, females=4. Intervention: Participants were tested in supine and seated positions (neutral,	1.	Test group comparisons: autonomically-complete SCI group had significantly lower systolic and diastolic arterial pressure, MCA diastolic and MCA mean cerebral blood flow velocities comared to the incomplete group (all p<0.05) Test groups to controls comparison: MCAdiastolic was significanty lower in autonomically-complete group (p<0.05).; Dastolic arterial pressure and mean arterial pressure were

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	lowered, and elevated) in the Elevation wheelchair. Outcome Measures: Blood pressure (BP); Heart rate (HR); Middle cerebral artery blood flow velocy (MCAv). All variables were measured using a of five- beat moving average. Additional variables measured were minimum blood pressure, timing of minimum blood pressure and overall orthostatic burden	3.4.5.6.7.	significantly higer (p=0.0015 and p=0.035) Movement from supine to seated position increased Systolic arterial pressure in controls (p< 0.001) and autonomically incomplete (p=0.024) Movement from seate to elevated postitions the mean systolic arterial pressure changed for the complete group only compared to supine (p=0.037) Movement to the lowered seated position increased systolic arterial pressure compared to standard seating and elevated for the complete group (p=0.029) Calculated cumulative orthostaic burden was not significantly different in the seated position, but was greater for the complete group in the elevated position compared to seated and lowered positions and compared to incomplete and control groups. (all p<0.05) HR increased from supine values during seated, elevated and lowered positions in all three groups (all p<0.05). In the autonomically-complete SCI group only, the HR in the elevated position was higher than in the seated
Lung et al. 2014 USA Pre-Post N=13	 Population: Mean age: 36.2 yr; Gender: males=9, females=4; Level of severity: AIS A=4, AIS B=2, AIS C=7; Mean time since injury: 5.8 yr. Intervention: Participants received a randomized order of six combinations of wheelchair tilt (15°, 25°, 35°) and recline (10° and 30°) angles. Participants were tested for each combination for 5 min, with an additional 5 min for both a baseline and recovery period before and after testing. Outcome Measures: Peak pressure displacement. Center of pressure displacement. 	1. 2. 3.	and lowered positions. Peak pressure displacement was not significantly different for any of the tilt- recline angle combinations (p>0.05). For center of pressure displacement there were significant differences for 10° and 30° recline for the following tilt angles: 15° versus 35° and 25° versus 35° (p<0.05). At 15°, 25° and 35°, center of pressure was significantly different between 10° and 30° recline (p<0.05).

The above studies have examined a variety of permutations of positions changes with outcome measures of interface pressure, blood flow and tissue perfusion to examine the effects of intentional position changes including lateral leaning, forward leaning and vertical push up and the use of positioning devices within the wheelchair frame including tilt, recline, tilt/recline combination and standing devices. The findings from each study have been synthesized into the following discussion sections where relevant; position changes of leaning and push-up, effects of wheelchair frame set-up, position change using recline only, position change using tilt only, and positions change using combinations of tilt, recline and standing.

Dynamic positioning devices such as tilt, recline and standing, have been identified as effective tools for assisting people to manage sitting pressures. However, the amount of position change required to offset the negative effects of sitting pressure is unclear. In the recent few years

many studies have been conducted to determine the optimal position change using interface pressure, blood flow and tissue perfusion. Of equal concern in the determination of the amount of position change required to affect sitting pressure is that of the required duration of the position change. This is important as the position change is often large, as highlighted in the subsequent studies related to position changes using these devices.

Position Changes: Leaning and Push-up

Summarized Level 5 evidence studies:

Yang et al. (2009) completed an observational study with the intent of describing the sitting behaviours of 20 people (18 men, two women) with spinal cord injury who use a manual wheelchair as their primary means of mobility and live in the community. Data was collected using a data logger and six force sensor resistors on the seat of the participants' own wheelchairs to track sitting contact on the wheelchair seat over a one-week period of time. The results indicated that on average these participants lifted off the seat surface once every one-two hours, sat for 9.2 hours a day, and sat for long periods of time without shifting weight (range of 97 minutes to 3.7 hours). The duration of the lift-off was reported so the benefit in relation to pressure management is not clear.

Sonenblum et al. (2016) also found that of the 28 people monitored in their everyday lives, that the weight shift frequency to meet the clinical guideline recommended criteria for pressure management, none of them met the criteria of every 15-60 minutes. Participants sat on average for 140 minutes +/- 84 minutes without shifting their weight at all. They also reported great variability in weight shifts across participants and for the same participant across days. Similar results were found by Sonenblum et al. (2018c) in their study of 29 adults who were 2 years post SCI. Participants were grouped based on pressure injury history. Findings indicated that weight shift movements that had potential to affect pressure management were performed less than once every 3 hours for both groups, with the no pressure injury history group completing slightly more pressure management weight shifts that the group with pressure injury history. Weight shifts that did not fully offload and in-seat movements occurred more frequently (1-2.5 and 39.6-46.5 times per hour respectively). Variability was noted as considerable for all movements across participants as well as for the same participant across days.

Discussion

The effectiveness of an intentional change in position by leaning or pushing up to lift the body from the seat surface is often determined by the ability to hold the position for an optimal duration of time. The following studies have examined weight shift behaviour, pressure changes associated with leaning and push-ups as well as the blood flow changes to determine the optimal duration of a position change.

In 1992 Hobson evaluated pressure changes during lateral trunk leaning to 15°, forward flexion to 50°, backrest recline to 120° and full body tilt to 20° (results from the tilt and recline positions are reported later). A 32% to 38% decrease in average pressure on the opposite side was found to occur during lateral trunk leaning. Moving into these alternate positions influenced the location of the maximum pressure, which was identified in the study as the ischial tuberosity location. An average 2.4 cm to 2.7 cm posterior shift occurred with forward trunk flexion. Maximum reductions in tangentially induced shear forces were also noted as occurring with forward trunk flexion of 50°. Hobson also noted that for the SCI population a 10% increase in pressure was observed up to 30° of forward flexion before the reduction began to occur.

Henderson et al. (1994) compared average pressures under the ITs and in a 71 mm x 71 mm area centered around the ITs in four different postures; upright resting posture, 35° and 65° tilt and 45° forward lean (participants were assisted into this position). The results of the tilt and recline positions are reported later. Forward leaning demonstrated a statistically significant (p<0.05) reduction of maximum point pressure to below 60 mmHg for eight out of 10 subjects and for seven out of 10 subjects below 32mmHg.

In a retrospective chart review of 46 SCI subjects seen in a seating clinic, Coggrave and Rose (2003) assessed the duration of various pressure relief positions required for loaded transcutaneous oxygen tension (t_cPO_2) to recover to unloaded levels. Results indicated that it took approximately two minutes of an intentional position change to raise tissue oxygen to unloaded levels for most subjects. This length of pressure relief was more easily sustained by the subjects leaning forward, side to side or having the wheelchair tipped back at $\geq 65^{\circ}$ compared to a push-up lift.

Similar to Coggrave and Rose (2003), Makhsous et al. (2007a) demonstrated full recovery of $tcPO_2$ with the dynamic protocol in the off-loading configuration but it took >two minutes to achieve this result. Those individuals with paraplegia using a wheelchair push-up were only able to sustain the lift for 49 seconds leading to incomplete recovery of tissue perfusion.

Lin et al. (2014) examined weight relief raises (WR) and shoulder external rotation protocol activities (ER) in relation to the subacromial space of the shoulder from an unloaded neutral position and the space before and after one minute of each of the above tested tasks. The repetition of 30 WR was suggested to be similar to that performed each day if the recommendations for weight shifting every 15 minutes were followed (of note, the study did not examine duration of the WR). While they did no find a difference in subacromial space pre-post, there was a significant narrowing during the WR. Additionally, they found that participants with increased years of SCI had a greater percentage of narrowing.

The results from the study by Smit et al. 2013, indicate that bending forward, leaning sideways and push-ups reduced interface pressure at the ITs and increased oxygenation at the subcutaneous level and increased blood flow. (The study also examined the effects of electrical stimulation on oxygenation which is addressed in an earlier chapter.) The authors propose that the results of this study further support that push-ups should no longer be recommended due to the impact on shoulder integrity, due to the equal benefits of bending forward and leaning to the side for decreasing IT pressure and increasing blood flow and oxygenation.

The results from the study by Sonenblum et al. (2014) also indicated that of five body position changes examined (small, intermediate and large forward lean and intermediate and large sideward lean) only the small forward lean did not have a significant effect on increasing blood flow and decreasing interface pressure at the IT. The effects were the same on all three cushion types tested (foam, gel and air), however they did find a difference in interface pressure on each cushion in upright sitting, with the foam cushion being significantly higher than the gel and air, but no significant difference between the gel and air cushions. The authors suggest that these findings indicate that body changes, (except small forward lean) are effective on any cushion type.

Wu and Bogie (2014) also found that changing body position such as leaning to the side, resulted in improvements in blood flow and tissue oxygenation and, reduction in interface pressure at the IT, however the benefits were not sustained, thus requiring regular and frequent repetition of the movements.

These studies suggest that changing body position by leaning to the side, forward or using a push-up result in decreased interface pressure to the un-weighted sitting area and increased blood flow to that of unloaded levels. Greater effect is seen if the position is sustained for greater than two minutes, which was not achieved by participants when using the push-up technique. Additionally, Lin et al. (2014) suggest that decreases in the subacromial space occur during the push up support limiting use of the vertical full body push up as a strategy for pressure management.

Conclusion

There is level 2 evidence (from one prospective control trial, one case control study, two pre-post study and three case series studies; Hobson 1992; Makhsous et al. 2007a; Sonenblum et al. 2014; Wu and Bogie, 2014; Smit et al. 2013; Coggrave & Rose 2003; Hendersen et al. 1994) to support position changes to temporarily redistribute interface pressure at the ischial tuberosities (IT) and sacrum by leaning forward greater than 45° or to the side greater than 15°.

There is level 4 evidence (from one case series study by Coggrave & Rose 2003; and two Pre-Post test studies by Smit et al. 2013; Hendersen et al. 1994) to support that a minimum two minute duration of forward leaning, side leaning or push-up must be sustained to raise tissue oxygen to unloaded levels.

There is level 3 evidence (from one case control study, two pre-post studies and one case series study; Makhsous et al. 2007a; Lin et al. 2014; Smit et al. 2013; Coggrave & Rose 2003) to support limiting the use of push-ups as a means for unweighting the sitting surface for pressure management.

Leaning forward at least 45° (elbows on knees position) or lateral trunk leaning to 15° reduces pressure and increases blood flow and tissue oxygenation at the sitting surface; it is important to be able to return to the original upright sitting position.

For most individuals with SCI, the use of a push-up/vertical lift is unlikely to be of sufficient duration to be beneficial for managing sitting pressure and has potential to contribute to repetitive strain injuries and a reduction of subacromial space.

Effects of Wheelchair Frame Set-up

Discussion

Only two studies examined how the set-up of the wheelchair frame influences sitting pressures. The first study by Maurer and Sprigle (2004) pressure mapped a common wheelchair frame configuration often used by the SCI population in which the front seat to floor height is higher than the rear seat to floor height while keeping the same back angle ("squeeze"). In this study, the difference between the front and rear seat to floor heights was measured in degrees or in inches; that measurement was used to identify how much squeeze there was in a wheelchair frame. The study found that there were no changes in peak pressures at the IT. The study also found that there was less pressure concentrated under the ITs, as the rear seat to floor height decreased but the total force on the seat increased. As part of the study protocol the participant

was seated with their sacrum up against the back support for all measures, but back support interface pressures were not measured.

Makhsous et al. (2007b) compared interface pressures on the seat and back between normal upright sitting and normal upright sitting alternated with partial ischial support removed. The results indicate a shift in interface pressure towards the middle and anterior seat when the posterior support is partially removed reducing the ischial pressure by as much as 40% for subjects with tetraplegia. Simultaneously, an increase in back support pressure was noted as the peak pressures and average pressures increased at the back support, suggesting a shift of interface pressure to the back support as well as to the anterior and middle aspects of the cushion.

These two studies suggest that the back support plays an important role in supporting the pelvis such that the area of pressure distribution can include the back.

Conclusion

There is level 4 evidence (one pre-post study Makhsous et al. 2007, one pre-post test study Maurer & Sprigle, 2004) to suggest the back support plays an important role in supporting the pelvis thereby increasing the area for pressure redistribution through the inclusion of the back surface.

There is level 4 evidence (one pre-post study and one pre-post test study; Makhsous et al. 2007; Maurer & Sprigle 2004) that sitting surface interface pressure decreases at the posterior aspect of the buttock as it is un-weighted however there is an increase in total force on the seat.

The back support plays an important role in pressure management on the sitting surface.

Position Change: Recline only

Discussion

In addition to examining maximum sitting pressure in relation to forward and lateral flexion, Hobson (1992) also examined changes in maximum sitting pressures in back support recline alone to 120° and full body tilt to 20°. The results for recline are reported here and results for tilt are reported in the associated section later in this chapter. When the back support was reclined to 120°, a 12% decrease in average maximum pressure occurred. However, this position influenced the location of the maximum pressure, which was identified in the study as the location of IT. The largest shift was 6 cm with back support recline to 120° with an increase in tangentially induced shear forces by 25% as compared to an average 2.4 cm to 2.7 cm posterior shift occurred with forward trunk flexion and a decrease in TIS.

Conclusion

There is level 4 evidence (one post-test, Hobson 1992) to suggest that back support recline to 120° decreases average maximum pressure in the ischial tuberosity area but also causes the greatest ischial tuberosity shift (up to 6 cm) and a 25% increase in tangentially induced shear forces.

Backrest recline alone to 120° decreased average maximum pressures in the ischial tuberosity area but also causes the greatest ischial tuberosity shift (up to 6 cm). Further research on the effect of friction/shear on the sitting surface in relation to the ischial tuberosity shift is required to determine if there is benefit in using backrest recline alone.

Position Changes: Tilt only

Discussion

Early studies in the examination of the effectiveness of position changes in managing sitting pressures tended to primarily use interface pressure mapping as the outcome measure. As noted in the previous sections, as part of the larger study Hobson (1992) also examined changes in maximum sitting pressures in full body tilt to 20°. The study reported an 11% decrease in maximum sitting pressures with maximum reductions in tangentially induced shear forces.

As noted above, Henderson et al. (1994) pressure mapped 10 SCI subjects and recorded pressures at the ischial tuberosity and the weight bearing surface area around the IT in four different postures; upright resting posture, 35° and 65° tilted position and 45° forward lean (the latter was discussed in the previous section). The results indicated that no significant changes in pressure occurred with the 35° tilt, but for wheelchairs tipped back 65° statistically significant pressure reduction at the IT and weight-bearing surface area (p<0.05) was demonstrated. It is worth noting here that the forward lean showed the greatest reduction (78% reduction at IT, 70% reduction on the weight-bearing surface area). Even with these significant changes in pressure, the pressure levels for only one subject reached 32 mmHg and only 3/10 subject's maximum point pressures were below 60mmHg.

Spijkerman et al. (1995) assessed interface pressure while individuals were tilted at 5°, 15° and 25° from horizontal. Results indicated that body tilt had a significant effect on mean pressure (p=0.003) with the lowest overall mean pressure (82.91 mmHg) being demonstrated at 25° tilt.

Geisbrecht et al. (2011) examined tilt using a manual tilt-in-space wheelchair. He found that compared to the upright position with back recline of 100° (baseline) there was a significant reduction in peak pressure index for the sacrum at 30° of tilt and greater. Geisbrecht et al. (2011) also compared participants with paraplegia to those with tetraplegia, with the only significant difference being that sacral pressures for participants with tetraplegia were significantly higher. For both groups, the peak pressure index at the ITs was significantly reduced at 30° of tilt and greater. Generally, a significant change in IT pressure was found starting at 30° of tilt with increasing amounts of tilt, resulting in greater the reduction in pressure at the sitting surface. The findings from this study are consistent with the changes in pressure findings in the study by Sonenblum and Sprigle (2011c).

Using participant's own wheelchair, Sonenblum and Sprigle (2011c) examined changes in interface pressure and blood flow on IT during varying degrees of tilt. Each tilt position was measured from an upright position (range of 0°-5° tilt). Small tilts of 15° did result in significant blood flow changes (8% increase) while interface pressures changed but did not reach a level of significance. Blood flow increased with each test situation of upright to 15°, upright to 30° and

upright to 45°. Tilting from 15° to 30°, did not result in an increase of blood flow, however interface pressure decreased. While blood flow increased at all degrees of tilt from an upright position, the amounts were variable across participants. Maximum blood flow increase was noted to be 10% which was achieved at 30° for four of the 11 participants, whereas others achieved a 10% blood flow increase at tilt greater than 45°. The authors noted a weak correlation between the increase in blood flow and pressure changes in tilt less than 30°, suggesting that there may be other mechanisms affecting blood flow other than pressure from the sitting load. An important factor noted by the authors is the need to consider the influence of the cushions used by the participants. Cushion type may influence blood flow and pressure loading of the buttocks on the seat surface. In this study, the participants used their own air floatation or gel cushions.

Conclusion

There is level 2 evidence (one randomized control test study by Sonenblum & Sprigle 2011c, one pre-post test study by Giesbrecht et al. 2011, one post-test Hobson 1992, two pre-post test studies Henderson 1994 and Spijkerman 1995) suggesting that there is an inverse relationship between tilt angle and pressure at the sitting surface and that significant reductions in interface pressure begins around 30° of tilt with maximum tilt providing maximum reduction of interface pressures. The amount of reduction realized was variable by person.

There is an inverse relationship between tilt angle and pressure at the sitting surface. Significant pressure redistribution realized was variable by person but on average started around 30° of tilt with maximum tilt providing maximum pressure redistribution.

Position Change: Combinations of Tilt, Recline and Stand

Summarized Level 5 Evidence studies:

Yang et al. (2014) completed an observational study (n=24) with SCI individuals to investigate the shear displacement between the body and backrest/seat, ROM and force acting on the lower limb joints during sit-stand-sit transitions by operating an electric-powered standing wheelchair. Each study subject completed three cycles of sit-to-stand, stand-to-sit with a oneminute break between cycles. Assessments conducted during the testing cycles included measuring the anterior and vertical forces acting on the knee restraint, degrees of sliding on the backrest and seat, and ROM of the hip, knee, and ankle. The study revealed that the forces acting on the knee restraint were significantly higher during the sit-to-stand transition compared to the stand-to-sit transition (p=0.01). The maximal and average anterior forces on the knee restraint was significantly greater during the sit-to-stand transition (p<0.01) but downward forces were significantly greater when returning to the sit position from standing (p=0.01). The range of sliding and displacement along the backrest was significantly larger during sit-to-stand transition (p<0.01) compared to stand-to-sit. During the stand-to-sit transition, the range of sliding and displacement along the seat was significantly larger (p=0.01) than the sit-to-stand transition. There were no significant differences reported between sit-to-stand and stand-to-sit in respect to hip ROM (p=0.59), knee ROM (p=0.71) and ankle ROM (p=0.78).

Mattie et al. (2017) observed how a group of 8 participants used the "on the fly" adjustable seat elevation and back support angle on an ultralight manual wheelchair. The findings identified that the back-support angle was infrequently adjusted, and the seat height use varied a great deal

across participants as well as per participant across days. The study authros suggest there is a need for adjustable features on manual ultralight wheelchairs for function.

Discussion

Sprigle et al. (2010) examined tilt, recline and standing using power positioning devices. Sprigle found a 46% reduction of seat pressure in 55° tilt, and a 61% reduction in pressure in full recline (180°) as well as in 75° of standing. The authors acknowledged that recline and standing offers a larger range of movement which likely contributes to the increased pressure reduction. The authors also noted there are contraindications in use of recline and standing that need to be considered before provision as a method to manage sitting pressure.

Similar to Sonenblum and Sprigle (2011c) (in tilt only section), Jan et al. (2010) also examined blood flow at the IT, however, did so during specific combinations of tilt and recline. Tilt at 15°, 25° and 35° were each combined with 100° and 120° of recline and compared to an upright position (0° tilt, 90° recline) to determine changes in blood flow. For 100° of recline, significant changes were found only in combination with 35° of tilt, which is not consistent with the study by Sonenblum and Sprigle (2011a) who found significant changes at 15° of tilt from upright. The combinations of 120° recline with 15°, 25° and 30° tilt produced significant changes in blood flow. The authors noted a significant increase in blood flow between the combinations of 120° recline with 15° tilt and 120° recline with 35° tilt; however, these comparisons are both from an upright position not moving from 15° to 35° of tilt so this finding needs to be applied carefully in daily life tilting situations. This is the same for the findings in which changing recline from 100° to 120° at both 25° and 35° tilt produced a significant increase in blood flow. The authors noted that results should only be generalized to tilt/recline in combination with foam cushions. This difference in cushion type may explain in part some of the differing results for blood flow between this study and the Sonenblum and Sprigle (2011c) study which used the participants' own air inflation and gel cushions.

The study by Jan and Crane (2013) found that sacral skin perfusion did not change significantly in any of the six variations of tilt/recline combinations as described in the above study by Jan et al (2010). The authors suggested that the expected increase in pressure over the sacrum was instead redistributed across the lumbar and thoracic area. However, it is worth noting that due to the small number of participants, care must be taken in generalizing the results of this study. It is also worth noting that the posture of the pelvis during testing was not described; the potential impact on pressure management by the effect the back support has the position of the pelvis has been noted earlier in the studies by Makhsous et al. (2007b) and Maurer and Sprigle (2004). Further research is required to make any recommendations.

The study by Jan et al. (2013a) compared muscle perfusion and skin perfusion during six different test positions of tilt and recline combinations. Larger amplitudes of tilt-recline combinations enhance skin perfusion over the ITs, but less perfusion is seen in the muscles during the same tilt-recline combinations. The authors indicate that this may suggest that muscle may be at greater risk for ischemia than skin if regular, adequate pressure redistribution is not achieved. Significant perfusion changes for skin or muscle were found for 15°, 25° and 35° tilt with120° recline and 35° tilt with 100° recline but no other combinations. It is worth noting that the risk of shear and friction often associated with recline use was not addressed in this study. It is also worth noting that testing was done on foam cushion with a standard power wheelchair not participants' own wheelchair and seating. As noted by Sonenblum and Sprigle (2011c) above differences in blood flow may be attributable to cushion type.

The study by Jan et al. (2013b) examined duration of position change. Results suggest that the duration of time spent in 35° tilt and 120° recline as part of a pressure management routine influences skin perfusion, with 3 minutes producing significantly higher skin perfusion than lesser times of one- or zero-minutes in. The study results also found the skin perfusion to be significantly higher during the second ischemic sitting period, but the study did not compare these results to the first ischemic period. This may be helpful to assist in determining the optimal time between pressure redistribution movements. It is worth noting that seven of the nine participants were an AIS C level of SCI injury so consideration needs to be given to the varying autonomic levels of function and the effect this may have on cardiac function and skin blood flow.

Lung et al. (2014) was part of the above studies but examined the effect of the various position configurations in relation to displacement of the peak pressure index (PPI), the displacement of the centre of pressure and the interface pressure mapping (IPM) sensel size used to capture this data. The authors related displacement to pelvic sliding, finding that PPI displacement ranged from 3.3cm to 6.6 cm, during the various position configurations. Based on these findings, the authors suggest the sensel window size needs to either be large enough (preferably 7x7) to capture displacement or it should be shifted to account for the displacement. They also did not find significant differences in PPI displacement between the positon configurations, suggesting that a particular angle does not necessarily produce a certain amount of PPI displacement. However, centre of pressure displacements was significantly different between the various position configurations to which the authors suggest may indicate differences in biomechanical changes for understanding individual differences in skin perfusion responses in different configurations of tilt and recline.

Inskip et al. (2017) explored the effects of seat elevation (similar to moving towards standing), seat lowering (similar to seat dump) and standard seat position as a means to determine impact on orthostatic hypotension. The findings suggest that those people who sustained an autonomically-complete SCI experience cardiovascular changes with positional changes, particularly moving into the elevated position. The authors suggest that there should be concern for cumulative burden of hypotension for this particular group especially for long periods of time. Conversely, findings suggest that moving into the lowered position from the elevated positin improved cardiovascular outcomes.

Conclusion

There is level 2 evidence (from three RCT Jan et al. 2010; Jan et al. 2013a; Jan & Crane 2013) to suggest that larger amounts of tilt alone or 15° tilt and greater in combination with 100° or 120° recline result in increased blood flow and decreased interface pressure at the ischial tuberosities (IT). There is inconsistency in the minimum amount of tilt needed to significantly increase both blood flow and interface pressure reduction. There is also limited evidence related to impact of shear forces with use of recline.

There is level 2 evidence (from two RCT studies Jan et al. 2013b; Sonenblum & Sprigle 2011c) to suggest that it cannot be assumed that changes in interface pressure through use of recline and/or tilt equates to an increase in blood flow at the IT or the sacrum.

There is level 2 evidence (from two RCT studies Jan et al. 2013b; Sonenblum & Sprigle 2011c) to suggest that muscle perfusion requires greater amplitudes of body position changes than that required for skin perfusion.

There is level 4 evidence (from one pre-post study; Lung et al. 2014) to suggest that peak pressure index, which is a common metric used in interface pressure mapping, displaces up to almost 7 cm during tilt and/or recline, therefore consideration for the size of the sensel window used to capture this data should either be large enough (7x7) or the location adjusted to ensure the data is fully captured.

There is level 2 evidence (one prospective controlled trial study by Inskip et al. 2017) that for people who sustained an autonomically complete SCI, that movement into a standing position for periods of time can make them vulnerable to severe orthostatic decreases in blood pressure.

It cannot be assumed that a change in interface pressure through use of tilt/recline equates to an increase in blood flow at the ischial tuberosities (IT).
The variability in blood flow and interface pressure changes associated with tilt/recline, supports the need for an individualized approach to education around power positioning device use for pressure management.
The type and duration of position changes for pressure management must be individualized
More research is needed to determine the parameters of position changes in relation to interface pressure and blood flow at the sitting surface tissues to help prevent pressure ulcers post SCI.
While power positioning technology including combinations of tilt, recline and stand, offer many health-related benefits, individualized assessment and thorough consideration of contraindications are required to ensure safe and appropriate use.
To mobilize knowledge related to pressure, and muscle/skin perfusion into clinical practice further research is needed to determine: 1) the influence of cushion type on muscle and skin perfusion; 2) the effects of friction and shear on skin and muscle perfusion and pressure during use of recline and/or tilt and/or standing; 3) the influence of postural deformities/tendencies on perfusion levels on both of the above and; 4) the effects of duration of large amplitudes of position changes within participants' regular daily routines of position changes.

7.0 Wheelchair Provision

Wheelchairs and scooters are critical devices to enable mobility among many people with spinal cord injury. However, the procurement process can be relatively complex as it frequently involves collaboration among people with spinal cord injury, their caregivers, device prescribers, and vendors (Mortenson & Miller, 2008). The World Health Organization identified eight critical steps for wheelchair provision, which includes 1) referral and appointment, 2) assessment, 3) prescription, 4) funding and ordering, 5) product preparation, 6) fitting/ adjusting, 7) user training, 8) follow-up, maintenance and repairs. For a wheeled mobility device to be fully integrated into the lives of potential users requires careful consideration of the user (i.e., their capabilities,), the activities that they want to perform (e.g., tasks, social participation), the characteristics of potential devices (e.g., dimensions, power options) and the environment in

which the device will be used (Mortenson & Miller, 2008). Funding is also an extremely important consideration given the cost of these devices (Mortenson & Miller, 2008).

 Table 24. Wheelchair Provision

Author Year Country Score Research Design Total Sample Size	Methods	Outcome
Samuelsson 2001 Sweden Pre-Post N=38	Population: Mean age: 43 yr; Gender: NA; Injury etiology: SCI=20, multiple sclerosis=7, stroke=4, cerebral palsy=4; spina bifida=3. Intervention: Patients who received client- specific, wheelchair modifications due to a problem with wheelchair seating were assessed before the modification and at a mean follow-up time of 6.5 mo. Outcome Measures: Effect of intervention on initial problem; Effect of intervention on other functionality aspects; Rhombo Medical Sensor Mess System (RMSMS); Visual Analogue Scale (VAS).	 The most prevalent problems requiring modification were seating discomfort (87%), back pain (63%), spinal deformity (26%) and pressure sores (18%). The most important functionality aspect described by patients was comfort at work followed by comfort at rest. A significant decrease in pain intensity according to the VAS was observed from pre to post-intervention in patients initially reporting back pain (p<0.001). All patients that initially reported pressure sores had a decreased maximum buttock pressure at follow- up according to the RMSMS. All issues reported were addressed positively or very positively in 79% of patients and 8% reported no difference or a negative effect of intervention. Seven patients did not accept the intervention at follow-up: 2 reported a negative effect of the intervention on other functionality aspects; and five reported no difference or a negative effect on their initial problem.
Kennedy 2003 UK Case Series N=50	 Population: Mean age: 41.1 yr; Gender: males=37, females=13; Level of Injury: complete paraplegia=13, complete tetraplegia=21, incomplete injury=16. Intervention: A retrospective review was conducted on patients that either received a specialized seating assessment (SSA) prior to their first Needs Assessment Checklist (NAC) (Group 1, N=30), received a SSA in between their first and second NAC (Group 2, N=11), or did not receive a SSA (Group 3, N=9). Outcome Measures: First and second assessment of the Needs Assessment Checklist (NAC): skin management subscale. Lower scores indicate lower levels of need (i.e., better outcomes). 	 Significant differences were observed between groups 1 and 3 in NAC scores at the first assessment (p<0.05) and the second assessment (p<0.01). Skin management scores were significantly lower at the second assessment of NAC compared to the first assessment in all groups (p<0.0001; p<0.01; p<0.01). Skin management scores were significantly lower in group 1 compared to groups 2 and 3 at both the first and second time points (p<0.05 for both).
Taylor et al. 2015 USA Observational N=1376	Population: Mean age: 38 yr; Gender: males=1115, females=261; Injury etiology: motor vehicle accident=688, fall/falling object=344, violence=151, sports=151, other=55; Level of Injury: tetraplegia C1- 4=393, tetraplegia C5-8=270.	 Wheelchair fitting sessions were completed by 98% of patients with assessment and fitting sessions provided by a physiotherapist being most frequent (65%).

Author Year Country Score Research Design Total Sample Size	Methods	Outcome
	paraplegia=499, other=214; Severity of Injury: AIS A-C=1140, AIS D=214. Intervention: Patients enrolled in the SCIRehab Project completed questionnaires from time of injury through to discharge along with a follow-up telephone interview at 1 yr post-injury. Data collected for the study focused on responses regarding training interventions/activities, adapted equipment, and equipment evaluation. Outcome Measures: Types of wheelchair training and skills learned, Types of fitting assessment, Adaptive equipment used, Wheelchair satisfaction.	 Of the 5% who did not receive wheelchair skills training during inpatient rehabilitation,44% reported no receipt of WC; Most people (80%) trained in manual wheelchair skills were prescribed a manual wheelchair only, 2% were prescribed a power WC only, and 10% were prescribed both types of chairs. A little over half (53%) of patients who received training only on power wheelchair and 33% reported prescription of both types of chairs. Almost half (48%) of patients who received training in both manual and power wheelchair skills reported prescription of both types of wheelchairs, 20% reported prescription of a power wheelchair and 28% reported prescription of only a manual wheelchair. 62% of the wheelchairs were received by the time of the patient's rehabilitation discharge and 98% were received by 6 mo-post discharge. Satisfaction with fit and function was reported among 87% of manual wheelchair users.
Ekiz et al. 2014 Turkey Observational N=27	Population: Mean age: 32.9 yr; Gender: males=25, females=2; Injury Etiology: motor vehicle accident=10, falls from height=9, gunshot=2, spinal mass=2, disaster injury=1, infection=1, other=2; Level of Injury: cervical=6, thoracic=18, lumbar=3; Level of severity: AIS A=21, AIS B=4, AIS C=1, AIS D=1. Intervention: Patient wheelchairs were examined by a physiatrist with parts such as armrest, headrest, wheels and seat belt evaluated along with ergonomic evaluations of seat length, seat depth, seat height, and back height. Outcome Measures: Correct setting and appropriateness of wheelchair parts, Functional Independence Measure (FIM).	 Seat height was found to be the most incorrect wheelchair measurement (18 wheelchairs (66.7%)). A total of 16 wheelchairs (59.3%) were found to have inappropriate cushions. Headrests were found to the most correctly set part of the wheelchair with 26 wheelchairs (96.3%) having appropriate headrests. Seat length was found to be the most correct wheelchair measurement (21 wheelchairs (77.8%)). FIM Motor score was not correlated with the amount of time spent in the wheelchair per day.
Groah et al. 2014 USA Observational N=359	Population: Mean age: 44.3 yr; Gender: males=274 Females=86; Level of Injury: C1-C4=48, C5-C8=121, T1-T7=85, T8- T12=80, L1-L5=20, unknown=5. Intervention: Patients from six SCI Model Systems centres participated in a face-to- face interview and completed a set of questionnaires. Patients were asked about the type of funding they received (e.g., Medicare, Medicaid, the Department of	 A significant difference was found between type of funding and proportion of patients who received lightweight customisable manual wheelchairs (p=0.04). There was a significant difference between private/prepaid and self-pay (p<0.05) and between Medicaid/DVR and self-paid (p<0.05) in the number of

Author Year Country Score Research Design Total Sample Size	Methods	Outcome
	Vocational Rehabilitation (DVR), workers compensation (WC), veteran's affairs (VA), private, pre-paid, or self-paid). Outcome Measures: Type of wheelchair, type of primary funding source.	 patients who received customizable lightweight manual wheelchairs. 3. No significant differences were reported between the number of patients who received customisable power wheelchairs and type of funding. 4. Significant differences were found between type of funding and level of injury (p<0.01). Patients with tetraplegia were more frequently covered by Medicare (65% versus34.5% whilst patients with paraplegia were more frequently covered by Medicaid/DVR (59.2% versus 40.8%), private/pre-paid (50.8% versus 49.2%), WC/VA (56.7% versus 43.3%), and self-paid (65.6% versus 34.4%).
Ambrosio et al. 2007 USA Observational N=2,154	Population: <i>SCI Group (n=791):</i> Mean age: 52.8 yr; Gender: males=775, females=16. <i>Multiple Sclerosis Group (MS, n=1363):</i> Mean age: 55.3 yr; Gender: males=1213, females=150. Intervention: Data on two Veterans Health Administration databases collected from 2000 to 2001 was analysed. The National Patient Care Database contained demographic information whilst the National Prosthetic Patient Database contained data regarding orthotic, prosthetic, and sensory devices distributed to patients. Outcome Measures: Types of wheeled mobility devices.	 Customised power wheelchairs were the most commonly prescribed power wheelchairs for SCI veterans with 36.3% of prescriptions. Ultra-lightweight manual wheelchairs were the most commonly prescribed manual wheelchairs for SCI veterans with 42.4% of prescriptions. Chi-square analyses revealed a significant difference between the SCI group and the MS group (p<0.001) in terms of the devices provided with the MS group being prescribed a greater number of scooters (39% versus12.8% of the SCI group), but fewer power chairs (33.7% versus43.7% of the SCI group) and manual wheelchairs (44,7 versus 49.8 of SCI group).
Di Marco et al. 2003 Australia Observational N=128	Population: NR. Intervention: Occupational therapy staff aimed to develop a standard of practice to guide wheelchair prescription and patient education. Education was provided on a one-to-one basis and focused on the needs of the patient. Follow-ups were completed at 3 mo and 12 mo. Outcome Measures: Patient participation, effectiveness of new standards and practice guidelines.	 A total of 86% patients chose to participate at the 3 mo follow-up and 79% participated at the 12 mo follow- up in the program. Staff noted that after teaching patients about wheelchair maintenance, the patients asked questions regarding advanced wheelchair adjustments such as changing the camber and balance of the wheelchair. Staff believed that follow-up times of 3 mo and 12mo allowed for ample time for the patients to test their wheelchairs and identify potential issues.

Discussion

Drawing on wheelchair related intervention data from 1,326 patients enrolled in the SCIRehab project, Taylor et al. (2015), found 98% of patients had a wheelchair fitting evaluation, the majority (62%) received their wheelchair prior to discharge and satisfaction with fit and function was >86% (Taylor et al. 2015). Groah et al. (2014) sought to identify insurance provider-related differences in the receipt of programmable power wheelchairs or customizable, lightweight manual wheelchairs among 359 individuals from six Spinal Cord Injury Model System centers. They found funding was associated with receipt of lightweight customizable manual wheelchair, but not power and there were significant differences in terms of level of injury and type of funding.

Drawing on data from 27 patients at the National Rehabilitation Center in Ankara, Turkey (Ekiz et al. (2014) found the majority had incorrect wheelchair seat height (66.7%) and inappropriate cushions (59.2%). However, the study did not provide details about how appropriateness was determined/operationalized; therefore, it is difficult to interpret the study findings or reproduce this work.

When comparing 1,363 veterans with MS and 791 veterans with SCI who had received wheeled mobility, Ambrosio et al. (2007) found that those with SCI received wheelchairs (manual and power) more frequently than those with multiple sclerosis (who received scooters more frequently). However, the authors did not attempt to control for differences in age or race (which varied between the groups) or other variables such as function

DiMarco et al. (2003) evaluated their clinical wheelchair provision practice in their SCI clinic, finding many inconsistencies. To address these issues, they developed and implemented a standard wheelchair service delivery process. Based data from 128 patients who attended their wheelchair SCI clinic, Di Marco et al. (2003) found that that return for follow up was high (79% at 12 months) which they attributed to their change in process. The article describes in detail the process they used to develop their service delivery process but statistical data are limited.

Kennedy et al. (2003) performed a retrospective chart analysis of patients who received, 1) a specialized seating assessment prior to their first needs assessment (a nine-category assessment of skin management, activities of daily living, bladder management, , bowel management, community preparation, wheelchair and equipment, psychological issues and discharge coordination), 2) a specialized seating assessment after their first needs assessment, or 3) did not receive a specialized needs assessments. They found patients who received a specialized seating assessment prior to their first needs assessment had lower skin management needs compared to those who received none. Without randomization, however, the causal nature of these claims cannot be verified.

Samuelsson et al. (2001) explored the outcomes of a client-centred wheelchair intervention among 38 patients attending a wheelchair clinic. They found that the intervention was associated with a significant decrease in pain and that initial problems were addressed positively for the majority of patients (Samuelsson et al. 2001). Given the study design there are a variety of threats to validity (e.g., maturation, attention bias); therefore, causality cannot be assumed as other factors may have caused these changes over time.

Conclusion

There is level 5 evidence (from three observational studies; Di Marco et al. 2003; Taylor et al. 2015 and Ekiz et al. 2014) to suggest that there are differences in the wheelchair provision process between service providers

There is level 5 evidence (from two observational studies; Groah et al. 2014 and Ambrosio et al. 2007) to suggest that diagnosis and funding is associated with the type of wheeled mobility received.

There is level 5 evidence (from one observational study; Di Marco et al. 2003) that suggests there is a benefit to following a standard process for wheelchair provision.

There is level 4 evidence (from one case series study; Kennedy et al. 2003, one pre-post study; Samuelsson et al. 2001 and one observational study; Taylor et al. 2015) to suggest that people who receive a specialized seating assessment and client centred interventions may experience better outcomes.

There is lower level evidence to suggest that people who receive specialized seating assessment and/or client-centred wheelchair interventions have better outcomes.

Gaps in the Evidence

- The influence of posture and positioning on the seat cushion needs to be explored, in static and dynamic movements as well as over the course of the day to account for the changes in posture and positioning that normally occur over the course of a day and across days.
- Clincially, there is a strong pressure-posture connection seen and the need to consider the wheelchair set up and how it effects the seating system is essential in clinical practice. However, it seems to be lacking in the current research. Further research is needed to explore the configuration of the wheelchair itself i.e. what angles and orientation the chair is set up with and how well this matches a client's needs for ROM, spasticity, balance and stability and function, as well as both the cushion and the backrest (individually as well as in combination) in terms of how they interface and support a client's posture. Exploring these factors as a whole and how it addresses not only pressure management but also postural management, comfort and function, which then can in turn have an additional influence on pressure management.
- There is research to support that changing body position as a pressure management strategy is prevalent as is the evidence to suggest body position changes are not being used with adequate frequency and duration, However, understanding why body position changes are not being used, both as a pressure management strategies and generally, is lacking.
- Best practice guidelines suggest the need for a comprehensive assessment by a knowledgeable health care provider, which is based on expert consensus; research evidence to support the expert consensus is lacking.

8.0 Summary

TO BE UPDATED AFTER ALL LOE COMPLETE

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Abbreviations

ADL	Activities of Daily Living
AIS	ASIA Impairment Scale
ARC	Arcing
ASB	Attachment to Standard Back support
ASIA	American Spinal Injury Association
BG	Bimanual Glider
BMI	Body Mass Index
CA	Total Contact Area
000	Custom Contour Cushions
CHART	Craig Handicap Assessment and Reporting Technique
CJ	Conventional Joystick
СОМ	Center of Mass
COP	Center of Pressure Displacement
СОРМ	Canadian Occupational Performance Measure
DFLCOP	COP state + position + velocity
DI	Dispersion Index
DLOP	Double looping over propulsion
EMG	Electromyography
FEW	Functional Every day with a Wheelchair
FSA	Forced Sensing Array
HFH	High Friction Elexible Handrim
ICE	International Classification of Functioning Disability and Health
IT	Ischial Tuberosities
ITS	Lateral Trunk Supports
MMT	Manual Muscle Testing
MP	Metacarpophalangeal
MWCU	Manual Wheelchair User Group
NMWCU	Non-Manual Wheelchair User Group
OT	Occupational Therapists
PAPAW	Pushrim-Activated Power-Assisted Wheelchairs
PIADS	Psychosocial Impact of Assistive Devices Scale
POposk	Peak Power Output
PPI	Peak Pressure Index
PRT	Pressure Relieving Tilt
PWC	Power Wheelchair
QUEST	Quebec User Evaluation of Satisfaction with Assistive Technology
ROM	Range of Motion
RPF	Ratings of Perceived Exertion
RSB	Replacement of Standard Back support
RSES	Rosenberg Self-Esteem Scale
SA	Seat Anterior
SB	Standard Back support
SC	Semicircular
SCI	Spinal Cord Injury

Spinal Cord Independence Measure III
Single looping over propulsion
Seat Posterior
Standardized Uncoated Handrim
Standard Wheelchair
Transcutaneous Partial Pressure of Carbon Dioxide
Transcutaneous Partial Pressure of Oxygen
Ultralight Wheelchair
Visual Analog Scale
Oxygen Uptake
Peak Oxygen Uptake
Wheelchair Outcome Measure
Partially removed ischial support and lumbar support