Reviewer ID: Nicole Elfring, Matthew Quer□e, Joanne Chi

Type of Outcome Measure: Hand-held dynamometer (HHD) □make technique (isometric), break technique (eccentric)

Total articles: 8

Author ID Year	Study Design	Setting	Population (sample size, age) and Group
Aufsesser et al. 2003	Reliability study using □make□technique bilaterally for biceps, triceps and wrist extension with individuals with SCI	VA Health Care System, Spinal Cord Injury Unit, La Jolla, California	N=25 Mean (SD) age: 52 (16); range: 25-83 Average (SD) length of injury in years: 13 (10); range: 1-34 19 right-handed, 6 left-handed all subjects at least 1 year post-injury 11 paraplegic 14 tetraplegics
Burns et al. 2005	Repeated-measures examining reliability of HHD for elbow flexor or extensors	Inpatient spinal cord injury unit	N=19 (all men) Mean (SD) age: 53.5 (11.7) 3 undergoing initial SCI rehabilitation (<6 months post-injury) 16 were >1 year post-injury Motor level: C4 □N=1 C5 □N=12 C6 □N=6 AIS scores: A □N=6 B □N=3 D □N=10 inclusion criteria: weakness of either the elbow flexor or extensor (MMT grade: 3 or 4 out of 5)
May et al. 1997	Repeated measures examining reliability of HHD for shoulder rotation	Private practice clinic	N=25 (21M, 4F) Mean (SD) age 26.6 (6.5) yrs (range 18-42yrs) 12 tetraplegia, 13 paraplegia. 22 traumatic SCI, 3 other (spina bifida, polio, tumor). Mean (SD) DOI 8.1 (6.9) yrs. Selected from various community groups.
Lamontagne et al. 1998	Methodological study. Inter-trial reliability of resistive torque measurements obtained w/ hand-held and isokinetic dynamometers were compared. Validity of hand-held dynamometer for assessment of spastic hypertonia was tested. Plantar flexors were stretched w/ an isokinetic dynamometer	Neurobiology Research Centre, Quebec, Canada	N=9 (6M, 3F) Mean age 40.6±10.5yrs (range 21-54yrs) All were subjects in an ongoing separate clinical trial. T6-10 Injury duration 1-5yrs. 7 complete, 2 incomplete 8 traumatic, 1 ischemic Ashworth score ≥1

	while evaluator tried to match velocities with a hand-held dynamometer. EMG of soleus and tibialis anterior muscles were taken.		
Jacquemin et al. 2004	Methodological study. Tests Maximal isometric contractions of intrinsic hand muscles (second-digit abductors, fifth-digit abductors and thumb opposers) via the break method 3 times each. 4 analysis methods: 1) max strength 2) median value of all 3 measurements 3) mean value of all 3 measurements 4) mean of the 2 highest measurements were evaluated for reliability.	VA SCI Service Veterans Affairs	N=55 31 AB subjects (17M, 14F) Mean age = 37.7yrs 29 right-hand dominant 24 subjects with SCI (23M, 1F) Mean age = 53.5yrs 16 right-hand dominant, 2 left-hand dominant, 6 unknown AB subjects were recruited at the veterans affairs. SCI subjects were in- or out-patients of the VA SCI Service. 9 had paraplegia, 14 had tetraplegia. Etiology of injury included cervical myelopathy or peripheral neuropathy due to median or ulnar nerve entrapment.
Herbison et al. 1996	Methodological study. Compares changes in strength after SCI with the use of a hand-held myometer to the manual muscle test (MMT). Tests elbow flexor muscles. Data collection times post-SCI were determined to be 72 h; 1, 2, 3 weeks; and 1, 2, 3, 6, 12, 18 and 24 months post spinal cord injury.	Regional SCI Centre of the Delaware Valley (patients recruited b/w 1988 and 1993).	N=88 (78M, 10F) Mean age=34yrs, range 15-68yrs. Level of injury C4-8. Frankel grades A-D. Inclusion criteria: Minimal manual muscle test (MMT) of 3.5 on one side.
Noreau & Vachon 1998	Methodological study. Purpose is to compare three methods for measuring upper limb muscle strength in individuals with SCI: the manual muscle test (MMT), the hand-held myometry and the	Rehabilitation Institute (Quebec City)	N=38 (31M, 7F) Paraplegia group: (N=23) mean age = 28.2±13.9yrs 18M 5F AIS level at admittance: A-15, B-3, C-1, D-4 Mean DOI at admittance: 1.6±0.7mo Tetraplegia group: (N=15) mean age = 30.1±13.4yrs

	isokinetic dynamometry (Cybex). Muscles tested were elbow flexors-extensors, shoulder flexors-extensors and shoulder abductors-adductors on the stronger side. The three procedures were performed at least 1 day apart over the course of 1 week.		13M 2F AIS level at admittance: A-6, B-6, C-3, D-0 Mean DOI at admittance: 2.1±2.1mo
Schwartz et al. 1992	Case series Purpose was to determine the relationship between the manual muscle test (MMT) and hand-held myometry and to define a range of myometry values that could be correlated with discrete MMT grades.	Hospital and home	N=122 individuals with quadriplegia (all male) Age range: 15-70 yrs old Frankel grades A-D Neurological level: C4-6

1. RELIABILITY

<table>
<tr><th>Author ID</th><th>Internal Consistency</th><th>Test-retest, Inter-rater, Intra-rater</th></tr>
<tr><td>Aufsesser et al. 2003</td><td>No data available</td><td>Reliability was examined across the three trials for each tester and the average of the trials was used to examine inter tester reliability.
Make technique

Intra-rater reliability □average of 3 trials:
Tester 1 ICC=0.93-0.99 (95% confidence interval: 0.87-0.97)
Tester 2 ICC=0.96-0.99 (95% confidence interval: 0.91-0.98)
Single-trial reliability was slightly lower, but still acceptable in the majority of cases.

Intra-rater reliability coefficients (R):
<table>
<tr><th></th><th colspan="2">Tester 1</th><th colspan="2">Tester 2</th></tr>
<tr><th>Muscle</th><th>Average R</th><th>Single-trial R</th><th>Average R</th><th>Single-trial R</th></tr>
<tr><td>Left biceps</td><td>0.93</td><td>0.82</td><td>0.98</td><td>0.95</td></tr>
<tr><td>Right biceps</td><td>0.99</td><td>0.96</td><td>0.96</td><td>0.90</td></tr>
<tr><td>Left triceps</td><td>0.98</td><td>0.94</td><td>0.99</td><td>0.97</td></tr>
<tr><td>Right triceps</td><td>0.96</td><td>0.88</td><td>0.99</td><td>0.97</td></tr>
<tr><td>Left wrist extensors</td><td>0.98</td><td>0.96</td><td>0.99</td><td>0.97</td></tr>
<tr><td>Right wrist extensors</td><td>0.98</td><td>0.94</td><td>0.99</td><td>0.97</td></tr>
</table>

Inter-rater reliability:
ICC=0.21-0.89
In all cases, when the lower bound 95% CI was considered, these coefficients were not</td></tr>
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acceptable.

Inter-rater reliability coefficient (R):

<table>
<tr><th>Muscle</th><th>Average R</th><th>Single-trial R</th></tr>
<tr><td>Left biceps</td><td>0.36</td><td>0.22</td></tr>
<tr><td>Right biceps</td><td>0.21</td><td>0.11</td></tr>
<tr><td>Left triceps</td><td>0.89</td><td>0.80</td></tr>
<tr><td>Right triceps</td><td>0.74</td><td>0.59</td></tr>
<tr><td>Left wrist extensors</td><td>0.84</td><td>0.73</td></tr>
<tr><td>Right wrist extensors</td><td>0.84</td><td>0.72</td></tr>
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</tr>
<tr>
<td>Burns et al. 2005</td>
<td>No data available</td>
<td>
For both make and break techniques, strength measurements showed high reliability for both interrater and intrarater reliability comparisons.

<table>
<tr><th></th><th>ICC:</th><th>95% confidence interval:</th></tr>
<tr><td>Intra-rater reliability:</td><td>--</td><td>--</td></tr>
<tr><td>Examiner 1 make</td><td>0.91</td><td>0.79-0.97</td></tr>
<tr><td>Examiner 2 make</td><td>0.94</td><td>0.86-0.98</td></tr>
<tr><td>Examiner 1 break</td><td>0.94</td><td>0.86-0.98</td></tr>
<tr><td>Examiner 2 break</td><td>0.93</td><td>0.82-0.97</td></tr>
<tr><td>Inter-rater reliability:</td><td>--</td><td>--</td></tr>
<tr><td>Examiner 1 make</td><td>0.94</td><td>0.86-0.98</td></tr>
<tr><td>Examiner 2 make</td><td>0.97</td><td>0.93-0.99</td></tr>
<tr><td>Examiner 1 break</td><td>0.95</td><td>0.87-0.98</td></tr>
<tr><td>Examiner 2 break</td><td>0.94</td><td>0.86-0.98</td></tr>
</table>

For these intra-rater comparisons, the mean difference in strength between the two sessions averaged between 1.0 and 1.5 kg. Within-participant standard deviation for the intrarater comparisons ranged from 0.8 to 1.3 kg, with no significant difference between make and break technique. The corresponding range for repeatability, 2.5–3.5 kg, indicates the maximum expected difference between two repeated measurements for 95% of paired observations. Within-participant standard deviation for the inter-rater comparisons ranged from 0.9 to 1.1 kg, with repeatability of between 2.6 and 2.9 kg, and there was no significant differences between repeatability for make and break techniques. Plots of differences between strength measurements for intra-rater and inter-rater comparisons showed no evidence of improved agreement later in the study, after the examiners gained experience with HHD.
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<tr>
<td>May et al. 1997</td>
<td>No data available</td>
<td>
Break test repeated three times for internal and external rotation on right and left shoulder. (All testing completed in one session.)

Intra-rater reliability assessed with ICC. Brackets indicate 95% confidence interval.
External rotation: all ICC=0.94 (.91-.96), paraplegics ICC=.89 (.80-.94), tetraplegics ICC=.93 (.86-.96)
Internal rotation: all ICC=.96 (.94-.98), paraplegics ICC=.92 (.86-.96), tetraplegics ICC=.89 (.81-.94)
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<tr>
<td>Lamontagne et al. 1998</td>
<td>No data available</td>
<td>
Resistive torque upon stretch of the plantar flexors was measured using a hand-held dynamometer (HHD) or a Kin-Com Isokinetic Dynamometer (ID). Ankle stretch was performed at set high (180°/s) or low (5°/s) velocities (this was estimated manually with the HHD).
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		Intraclass correlation coefficients. <u>HHD:</u> ICC's for movements at low velocity were similar whether all trials were included (n=5; ICC=0.93) or the first trial was excluded (n=4; ICC=0.94). ICC's for movements at high velocity were also similar when all trials were included (ICC=0.84) or the first trial was excluded (ICC=0.81), but were lower than low velocity ICC's. <u>ID:</u> ICC's were higher when the first trial was excluded (low velocity: ICC=0.99; high velocity: ICC=0.93) compared to when it was included (low velocity: ICC=0.83; high velocity: ICC=0.75). Similar to HHD, ICC's were lower for the high velocity movements. **Intertrial variability was expressed with Coefficients of variation (as a percentage) using the last four trials.** CV's were generally higher for the HHD method compared to the ID method. Resistive torque: Low velocity CV=7.98 (HHD) and CV=3.14 (ID) High velocity CV=16.11 (HHD) and CV=6.43 (ID) Velocity: Low velocity CV=40.43 (HHD) and CV=7.84 (ID) High velocity CV=12.74 (HHD) and CV=0.47 (ID)
Jacquemin 2004	No data available	*Bilateral measurements were made by two testers, three times each for each of the muscle groups (second digit abductors, fifth digit abductors and thumb opposers).* **Bland-Altman plotting method.** Inter-rater differences varied with the level of strength (more variance at higher strength), but differences relative to strength were similar except at strength levels below 1.0kg. Values below 1.0kg were excluded for 95% interval calculation. The mean of the highest of 2 of 3 trials was used to define the upper limit (95^{th} percentile) of normal inter-rater differences with 29.3, 38.5 and 43.7% for second digit abductor (2^{nd} abd)., fifth digit abductor (5^{th} abd) and thumb opposition (1^{st} opp), respectively. This study suggests that serial strength differences exceeding these values are likely to represent significant changes in muscle strength. 95^{th} Percentile of Interraters differences Max strength: 35.8 (2^{nd} adb), 40.0 (5^{th} abd), 43.7 (1^{st} opp) Mean of 2 highest: 29.6 (2^{nd} adb), 38.5 (5^{th} abd), 43.7 (1^{st} opp) Mean of 3: 29.3 (2^{nd} adb), 35.0 (5^{th} abd), 38.6 (1^{st} opp) Median of 3: 31.9 (2^{nd} adb), 40.0 (5^{th} abd), 43.7 (1^{st} opp)
Herbison et al. 1996	No data available	Inter-rater reliability for myometer testing was 0.82.
Schwartz et al 1992	No data available	Sequential motor strength examination using both MMT and hand-held myometry were performed at 72 hours, 1 and 2 weeks and 1, 2, 3, 4, 6, 12, 18 and 24 months post-injury. Inter-rater reliability for all muscles tested was r=0.94.
2. VALIDITY		
Author ID		

May et al. 1997	*The averages of three HHD measurements were compared to the averages of four trials with an isokinetic dynamometer.* **Pearson correlation coefficient.** All correlations were significant (P<.0001 for whole group comparisons; P<.01 for groups by SCI type). External rotation: all r=0.86, paraplegics r=0.83, tetraplegics r=0.56 Internal rotation: all r=0.88, paraplegics r=0.74, tetraplegics r=0.52 The Pearson product moment correlation as calculated for the combined data of all subjects was .88 for internal rotation and .86 for external rotation. Both correlations were significant at the p < .0001 level, indicating a good relationship between the HHD and Cybex measurements. Separate analyses of the paraplegia and tetraplegia data found significant correlations (p < .01); however, the coefficients for the data of the persons with tetraplegia were considerably lower than those calculated for the persons with paraplegia.
Jacquemin 2004	*Strength measurements compared to those obtained with Manual Muscle Test (MMT; graded scores from 0 to 5).* Scores by these two methods were positively correlated, but were nonlinear with a marked dispersion of values at MMT grades 3, 4 and 5. This indicates a lack of sensitivity of the MMT method at those higher strength ranges, whereas myometry detected changes within this range.
Herbison et al. 1996	*Hand held myometry (MYO) and manual muscle testing (MMT) were performed at various intervals between 72h to 2 years post-SCI. Groups were based on changes (half or full grade) from initial to later MMT score. For each interval, the later MYO measurement (MY02) was divided by the earlier (MYOI). The result was multiplied by 100 to obtain a value which expressed the later strength of contraction as a percent of the earlier examination.* **Student t-tests were used to compare MYO1 and MYO2 values. Measures were expressed as geometric means (GM; MYO2/MYO1 x 100) and coefficients of variation of these % changes (CV).** MYO was more sensitive than MMT in detecting strength changes. Values indicate (GM-1 CV; GM; GM+1CV; significance level). a) Two of the three groups that had no change in MMT scores had significant changes in MYO scores □ MMT=4.0 (80; 140; 243; p<0.05), MMT=4.5 (84; 126; 187; P<.01). b) There were also larger changes indicated by MYO for groups that made a half grade change in MMT scores □ MMT=3.5-4.0 (123; 205; 342; P<.002), MMT=4.0-4.5 (82; 139; 234; P<.02) and MMT=4.5-5.0 (84; 126; 187; P<.02). c) There were also larger changes indicated by MYO for groups that made a full grade change in MMT scores □ MMT=3.5-4.5 (127; 232; 424; P<.05) and MMT=4.0-5.0 (126; 191; 292; P<.001).
Noreau & Vachon 1998	*Measured elbow extension and flexion, shoulder extension and flexion, and shoulder adduction and abduction. The three tests were separated by at least one day and were all performed within a week.* *Manual muscle test (MMT) □ graded from 0 to 5* *Hand-held myometer (HHM) □ avg of three trials for each muscle group* *Isokinetic dynamometry (ID) - 60□/sec, tested stronger side of body* **Spearman correlations for comparison of MMT and HHM.** Paraplegics r=0.26-0.67 Tetraplegics r=0.50-0.95 Highest correlations were for elbow extension and shoulder flexion and adduction in tetraplegics at admittance (r=0.95, 0.83, 0.84, respectively). The majority of correlations decreased at time of discharge. Spearman correlation coefficients between the strength values measured by MMT and myometry for six muscle

	groups (tested on both sides) in individuals with SCI (n=38):

	Paraplegia (n=23)		**Tetraplegia** (n=15)	
Muscles:	**Admittance**	**Discharge**	**Admittance**	**Discharge**
Elbow flexors	0.48	0.26**	0.58	0.48*
Elbow extensors	0.46	0.55	0.95	0.88
Shoulder flexors	0.63	0.60	0.83	0.50*
Shoulder extensors	0.44*	0.49	0.67	0.57
Shoulder abductors	0.64	0.57	0.55*	0.59
Shoulder adductors	0.67	0.34*	0.84	0.73

*.001<P<.05
**P=.084
P<=0.001 if not indicated

Spearman correlations for comparison of MMT and ID.
Paraplegics r=0.19-0.65
Tetraplegics r=0.35-0.95

Pearson correlations for comparison of HHM and ID.
Paraplegics r=0.70-0.90
Tetraplegics r=0.57-0.96
Lowest correlations were for elbow extension and shoulder abduction (paraplegics) and shoulder extension and abduction (tetraplegia). These correlations increased at discharge (as well as shoulder adduction in paraplegics).

Pearson correlation coefficients between the strength values measured by myometry and ID on 6 muscle groups (tested on stronger side) in individuals with SCI (n=38):

	Paraplegia (n=22, missing one value)		**Tetraplegia**	
Muscles:	**Admittance**	**Discharge**	**Admittance**	**Discharge**
Elbow flexors	0.76	0.75	0.81	0.75
Elbow extensors	0.70	0.82	0.92	0.96
Shoulder flexors	0.89	0.89	0.82	0.78
Shoulder extensors	0.85	0.83	0.59*	0.87
Shoulder abductors	0.73	0.82	0.57*	0.76
Shoulder adductors	0.81	0.90	0.91	0.90

Schwartz et al. 1992

Spearman rank correlation coefficients were performed looking at the MMT and myometry measurements.

Of the 24 correlation obtained between the two measures, 22 were significant (p<0.001). Correlations ranged from 0.59 to 0.94. The 2 non-significant correlations occurred at 12 months for the right biceps (r=.18) and left biceps (r=.42).
Spearman rank correlation between MMT and Myometry: time post SCI

Muscle:	**72 hours**	**1 week**	**1 month**	**3 months**	**6 months**	**12 months**
Left bicep	0.86	0.84	0.68	0.82	0.59	0.42
Right bicep	0.80	0.83	0.79	0.68	0.59	0.18
Left ECR	0.92	0.86	0.81	0.84	0.84	0.77
Right ECR	0.94	0.78	0.93	0.79	0.75	0.71

Correlation analysis found both modalities were measuring the strength of the muscle, but the myometry measured more subtle changes in muscle strength.

MMT data has a smaller increase from date of injury to 24 months post-injury, while myometry data reflect a steady increase in strength. This suggests that the MMT cannot detect small changes in strength. Schwartz proposes that this is because in order to receive a grade of 3.0 by the MMT method, only a small fraction of the motor neurons need to be functional while MMT strength grades above a 3.0 require activation of the majority of the remaining neurons.

3. RESPONSIVENESS – no data available

4. FLOOR/CEILING EFFECT – no data available

5. INTERPRETABILITY

Author ID	Interpretability
Aufsesser et al. 2003	Root mean square error (RMSE) was calculated to determine if the measurement error was tolerable. Results indicated RMSE range for each tester for intra-rater reliability testing: Tester 1: 2.97-5.39 lb Tester 2: 1.72-3.15 lb Root mean square error (RMSE) was calculated to determine if the measurement error was tolerable. Results indicated RMSE range was very high (ranging from 5.70 lb for left triceps to 13.91 lb for right biceps). Mean (SD) measurements, SEM and MDC for each tester: (SEM and MDC calculated from data in Aufsesser et al. 2003 – single-trial intra-rater used)

	Tester 1			Tester 2		
Muscle	**mean (SD) measurement (lbs)**	**SEM (lbs)**	**MDC (lbs)**	**mean (SD) measurement (lbs)**	**SEM (lbs)**	**MDC (lbs)**
Left biceps	46.79 (11.91)	5.05	14.01	37.92 (8.23)	1.84	5.10
Right biceps	46.20 (14.70)	2.94	8.15	34.97 (9.37)	2.96	8.21
Left triceps	26.28 (11.90)	2.91	8.08	26.33 (12.51)	2.17	6.01
Right triceps	30.74 (9.41)	3.26	9.04	27.21 (14.09)	2.44	6.76
Left wrist extensors	32.80 (13.55)	2.71	7.51	23.26 (10.00)	1.73	4.80
Right wrist extensors	31.39 (11.99)	2.94	8.14	23.05 (10.52)	0.26	0.73

Author ID	Interpretability
Burns et al. 2005	The break technique produced significantly greater strength measurements than did the make technique. We calculated this difference as the break/make (B/M) ratio. B/M ratios showed considerable variability between participants, and there was no significant difference in mean B/M ratios determined by the two examiners. For examiner 1, mean (SD) B/M was 1.41 (0.39) in session 1 and 1.48 (0.38) in session 2, with corresponding values of 1.38 (0.29) and 1.49 (0.37) for examiner 2. We found no association between the B/M ratio and either the DTR or MAS for the test muscle.
May et al. 1997	Mean (SD) hand-held dynamometer measurements in kg for different shoulder movements:

Shoulder movement	**mean (SD) measurement (kg)**
External rotation (all subjects)	16.8 (7.3)
Internal rotation (all subjects)	22.8 (9.9)
External rotation (paraplegia)	21.5 (6.4)
External rotation (tetraplegia)	11.7 (4.5)
Internal rotation (paraplegic)	30.1 (6.9)
Internal rotation (tetraplegia)	14.8 (5.5)

Author ID	Interpretability
Schwartz et al. 1992	Mean (SD) myometry data grouped by MMT score:

	Acute period (72 h-2 weeks)				Rehabilitation period (2mo – 3mo)			
MMT score:	**Left bicep**	**Right bicep**	**Left ECR**	**Right ECR**	**Left bicep**	**Right bicep**	**Left ECR**	**Right ECR**
2.5-3.5	2.8 (1.7)	2.4 (2.7)	2.9 (1.8)	2.1 (1.3)	5.1 (2.8)	5.8 (5.3)	5.0 (2.4)	3.7 (1.3)
4.0	2.8 (1.5)	5.6 (2.2)	4.8 (1.1)	3.5 (2.1)	8.6 (2.6)	12.2 (1.1)	8.6 (2.0)	8.7 (6.9)
4.5-5.0	8.9 (4.2)	8.7 (4.4)	6.2 (3.3)	7.3 (4.2)	9.5 (3.2)	10.2 (3.9)	10.8 (0)	6.2 (2.0)

Last Updated: July 17, 2019

								*n=1		