SCIRE

SPINAL CORD INJURY REHABILITATION EVIDENCE

Imaging Aspects of Spinal Cord Injury

Sebastiano Failla
Manas Sharma
Ruba Kiwan
Yasmine Sallam
Ian Chan
Olivia Li
Arthur Wozniak
Robert Teasell

Key Points

Magnetic Resonance Imaging

- MRI is an effective diagnostic tool to assess damage to microstructures within the spinal cord as well as detecting other indications of damage such as hemorrhage and edemas.
- MRI may be reliably used to predict an individual's injury severity, American Spinal Injury Association score, motor score, AIS, and neurologic outcome given an SCI
- For individuals with SCI without radiographic abnormality MRI may not be useful in determining current injury severity or predicting outcome following injury.

Diffusion Tensor Imaging

- DTI has value as a diagnostic imaging tool to evaluate microstructural and spinal cord abnormalities in individuals with SCI.
- There is conflicting evidence as to which observations from DTI can be used to predict current and future outcomes.
- DTI may be effective for predicting relationships between different SCI abnormalities within individuals.

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Imaging of Spinal Cord Injuries

1.0 Executive Summary

Overall studies using magnetic resonance imaging (MRI) and diffusion tensor imaging (DTI) provide strong evidence that these are important imaging tools in the diagnosis, prognosis, and evaluation of injuries associated with SCI. MRI was shown to have high sensitivity and specificity in the detection of microstructural abnormalities related to SCI, and that these observations can be used to predict motor score and classification. There is limited evidence to suggest that MRI may be useful in the diagnosis and prognosis of motor classification in individuals with SCI without radiographic abnormalities. With respect to DTI, there is strong evidence to support its use as a diagnostic tool, however the evidence surrounding its use as a prognostic indicator are mixed. In general, there are fewer studies reporting the use of DTI in relation to SCI management compared to the use of MRI.

2.0 Methods

A key word literature search for scientific articles published between January 1, 2015 to August 31, 2018 investigating the use of imaging tools in the diagnosis and management of SCI was conducted using the following online databases: MEDLINE, CINAHL, Scopus, EMBASE and Cochrane Library. Population key words (i.e., spinal cord injury, quadriplegia, hemiplegia, and tetraplegia) and imaging key words (i.e., magnetic resonance imaging, CT, computed tomography, radiograph, x-ray, and imaging) were used. The search was limited to journal articles, reviews, or systematic reviews (excluding case reports) which were published in English, had a minimum sample of three adults (≥18 years) with an SCI. The SCI population within each study must have comprised of at least 50% of the total study population, unless results were stratified. A total of 4762 studies were found that satisfied the search criteria, after the removal of duplicates, animal and pediatric studies, and case reports 34 studies remained. Studies were considered appropriate for inclusion in this chapter if the majority of participants were within 3 months post-SCI. Articles were then further subdivided into groups based on the imaging technique used.

3.0 Introduction

Imaging plays a critical role in the diagnosis, treatment and rehabilitation of individuals with SCI. Conventional imaging tools have provided anatomical information leading to more targeted and overall better management of these individuals no doubt, but more recent development of advanced imaging techniques are capable of providing microstructural and metabolic information as well. Conventional radiography and computed tomography (CT) give macro-structural information about bony structures mainly, critical for the vertebral column. Comparison of different imaging modalities helps understand appropriate use, risks and benefits of each, financial aspects and radiation issues involved, all leading to avoidance of unnecessary delay in more advanced care or treatment.

Prognosis of SCI is discussed in brief. Moreover, the psychometrics of MRI related to sensitivity, specificity, and interrater reliability are explored. More modern techniques capable of providing microstructural information built mostly upon these basic anatomic imaging tools are now available in many places and in a short subsection we discuss DTI and its role in identifying SCIs. Many more modern techniques, such as spectroscopy and perfusion MRI, are used in the research domain and are not currently being used in clinical practice, therefore, are not evaluated here. The following chapter will review contemporary clinical roles of non-invasive imaging pertaining to spinal cord injury, as well as, their role, prognostic and diagnostic.

4.0 Radiography and Computed Tomography (CT)

Plain radiographs use x-rays to create an image of the body using various projections (frontal, lateral). Plain radiographs play a rather limited role in today's assessment protocols for SCI, but nevertheless retain value as a quick screening tool in many situations and also are a quick way of assessing instability of the vertebral column with flexion, neutral position and extension views easily obtainable. CT is the best modality for assessment of bony details but remains rather limited for cord assessment. CT is a modality that uses x-rays to create cross-sectional images or slices of the body.

5.0 Magnetic Resonance Imaging (MRI)

MRI is an imaging modality that uses non-ionising radiation to construct useful diagnostic images. MRI with superior soft tissue resolution gives critical information on ligamentous, soft tissue and cord injury and is currently the gold standard for soft tissue assessment. Here in this chapter, we discuss MRI for assessment of traumatic SCI. MRI is the imaging modality of choice to diagnose acute cord compression and its effects in SCI.

Table 1 Diagnosis and Prognostication with MRI

Author Year Country Research Design Score Total Sample Size	**Methods**	**Outcome**
Diagnostic Value		
Yasin et al., (2017) Pakistan Observational N=38	**Population**: *SCI (n=10):* Mean age=28.35±7.67yr; Gender: males=31, females=7; Level of injury: C=12, L=16; Mean time since injury=4.98±3.84d; AIS scale: NR. **Intervention:** Individuals suspected of SCI underwent magnetic resonance imaging (MRI) for diagnosis. **Outcome Measures:** Sensitivity; specificity; predictive value; diagnostic accuracy.	1. MRI is a highly sensitive and accurate technique 2. Sensitivity=96.55% 3. Specificity=88.89% 4. Predictive value=96.55% 5. Diagnostic accuracy=94.74%
Ghasemi et al., (2015) Iran Observational N=40	**Population**: SCI (n=40): Mean age(men)=43.56±18.82yr; Mean age(women)=48.47±20.45yr; Gender: males=25, females=15; Level of injury: C=3, T=9, L=14; thoracolumbarsacral=3; unaffected=11; Mean time since injury=≤24hr; AIS scale: NR.	1. For SCI with edema, MRI without contrast had specificity, PPV, NPV, PL, and NL of 75%, 100%, 100%, 94.11%, and 68.4%, respectively. 2. For SCI with edema MRI with contrast had specificity, PPV, NPV, PL, and NL of 100%, 100%, 100%, 100%, and 0%, respectively.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Intervention: Two stages of magnetic resonance imaging (MRI) was performed on all individuals (one with contrast and one without). MRI was obtained using a 1.5T system with a spine coil. Images were acquired using sagittal T1 and T2 sequences. Psychometrics were obtained for various spinal cord injury patterns. **Outcome Measures:** Specificity; positive predictive value (PPV); negative predictive value (NPV); positive likelihood (PL); negative likelihood (NL).	3. For SCI with hemorrhage, MRI without contrast had specificity, PPV, NPV, PL, and NL of 100%,100%,100%, 100%, and 0%, respectively. 4. For SCI with hemorrhage, MRI with contrast had specificity, PPV, NPV, PL, and NL of 50%, 100%, 100%, 0.44%, and 13%, respectively. 5. For SCI with combination of hemorrhage and edema, MRI without contrast had specificity, PPV, NPV, PL, and NL of 0%, 100%, 0%, 0.60%, and 6%, respectively. 6. For SCI with combination of hemorrhage and edema, MRI with contrast had specificity, PPV, NPV, PL, and NL of 100%, 100%, 100%, 100%, and 0%, respectively.
Karpova et al., (2013) Canada Case series N=17	**Population:** *Cervical Myelopathy (n=17):* Mean age=54.5yr; Gender: males=13, females=4. **Intervention:** To assess the intra-and inter-observer reliability of commonly used quantitative magnetic resonance imaging (MRI) measures such as transverse area (TA), compression ratio (CR), maximum canal compromise (MCC), maximum spinal cord compression (MSCC). **Outcome Measures:** Intra-class correlation coefficients (ICC).	1. The mean±SD for intra-observer ICC was 0.88±0.1 for MCC, 0.76±0.08 for MSCC, 0.92±0.07 for TA, and 0.82±0.13 for CR. 2. Additionally, inter-observer ICC was 0.75±0.04 for MCC, 0.79±0.09 for MSCC, 0.80±0.05 for CR, and 0.86±0.03 for TA.
Prognostication		
Seif et al., (2018) Switzerland Case Control N=47	**Population**: SCI (n=24): Mean age=49.7±19.8yr; Gender: males=19, females=5; Level of injury: C=12, T=9, L=2, S=1; Mean time since injury=45.6±20.7d; AIS scale: A=6, B=5, C=4, D=9. Healthy controls (n=23): Mean age=35.9±10.9yr; Gender: males=13, females=10; Level of injury: N/A; Time since injury=N/A; AIS scale: N/A. **Intervention:** All participants underwent magnetic resonance imaging (MRI) using a 3T system. Sequences included T1-weighted 3D magnetization Prepared Rapid Acquisition Gradient-Echo (IMPRAGE) of the whole brain extending to the cervical C5 level (field of view=224 X 256, matrix=224 X 256, repetition time/echo (TR/TE)=2420/4.18 ms, bandwidth=150 hz/pixel). Microstructural changes were assessed with three different 3D multi-echo fast low-angle shot (FLASH) gradient-echo sequences.	1. There was a significant association between baseline APW and LEM at 2 mo (r^2=0.97, p=0.03). 2. There was also a significant association between RI of the cord and pinprick score at 12 mo (r^2=0.71, p=0.04). 3. SCA (p=0.004) and APW (p=0.005) were significantly lower compared to controls at baseline. There was no significant difference in LRW between the two groups at baseline (p=0.67). 4. There were no significant differences in microstructural measures of MT, R1, and R2 in the cervical cord when comparing SCI to controls (p>0.05).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Participants were assessed at baseline, 2, 6, 12, and 24 mo post-SCI. **Outcome Measures:** Cross-sectional **s**pinal cord area (SCA); anterior-posterior width (APW); left-right width (LRW); lower extremity motor score (LEM); Microstructural parameters: magnetization transfer (MT); longitudinal relaxation rate (R1); effective transverse relaxation rate (R2).	
Dalkilic et al., (2018) Canada Observational $N_{Initial}$=36 N_{Final}=34	**Population**: SCI (n=36): Mean age=42.1±13yr; Gender: males=23, females=13; Level of injury: C=36; Mean time since injury=12.87hr; AIS: A=20, B=7, C=9. **Intervention:** Individuals were assessed using magnetic resonance imaging (MRI) pre-operatively with a 1.5T MRI system. Conventional MRI sequences included were fast-spin-echo (FSE) T1-weighted sagittal image with repetition time/echo time(TR/TE) =533/10ms, T2-weighted sagittal image with TR/TE=3000/84ms, FSE T2-weighted axial image with TR/TE=3390/98ms, and T2 gradient echo weighted axial image with TR/TE=1030/24ms. AIS grade was assessed pre-operatively (baseline) and 6mo post-injury. Outcome measures below were assessed by MRI. **Outcome Measures:** Intramedullary lesion length (IMLL); hematoma length; CSF effacement length; cord expansion length; maximal cord compression (MCC).	1. Hematoma length (p=0.006), CSF effacement length (p=0.007), and cord expansion length (p=0.031) differed significantly between individuals with baseline AIS grades A, B, and C. There were no significant differences in IMLL and MCC (p>0.05). 2. A logistic regression model of MRI found that only CSF effacement and hematoma length were statistically significant predictors of baseline AIS grade (p<0.05). The model had 72.2% accuracy for AIS grade classification. 3. IMLL (p=0.031) and hematoma length (p=0.002) were significantly higher in individuals who converted their AIS grade within 6mo compared to those who did not. CSF effacement, cord expansion length, and MCC did not differ significantly between the two groups (p>0.05).
Aarabi et al., (2017) USA Observational N=100	**Population**: SCI (n=100): Mean age=39.5±16.8yr; Gender: males=89, females=11; Level of injury: C=100; Time since injury: ≤12hr=51, >12hr=49; AIS: A=52, B=29, C=19. **Intervention:** Individuals who underwent surgical spinal cord decompression were included in this longitudinal, retrospective study. AIS grade was re-evaluated at 6wk, 3mo, 6mo, and 12mo following discharge. Post-operative magnetic resonance imaging (MRI) was used to assess outcome measures. Outcome measures below were assessed by MRI. **Outcome Measures**: AIS grade conversion at 6mo post-surgery; Intramedullary lesion length (IMLL); evidence of decompression; presence of intramedullary hematomas.	1. IMLL was a significant predictor of AIS impairment scale grade conversion at 6mo in univariate (p<0.001) and sole predictor in multivariate (OR=0.950, CI: 0.931-0.969) analysis. The multivariate model predicted 5% and 40% decreases in the odds of AIS scale grade conversion for 1-and 10mm increases in IMLL, respectively. 2. Univariate analysis showed that the presence of intramedullary and evidence of decompression were significantly related to AIS grade conversion at 6mo (p<0.001), however, were not significant in multivariate analysis (stepwise multiple logistic regression) (p>0.05).
Martinez-Perez et al., (2017) Canada	**Population**: Incomplete SCI (n=86): Mean age=47.6yr (range=18-87); Gender: males=68, females=18; Level of	1. LOE >36mm was significantly associated with poor neurological

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Observational N=86	injury: C=86; Time since injury=<72hr for all; AIS at admission: B=12, C=29, D=35, E=38. **Intervention:** This retrospective review examined individuals who presented with acute incomplete cervical SCI secondary to blunt trauma. Magnetic resonance imaging (MRI) was performed at initial diagnosis using a 1.5T system. Axial and sagittal planes had a slice thickness of 3mm. Image sequences included axial T1-weighted, T2-weighted, and gradient echo images, as well as sagittal T1-weighted, T2-weighted, and short tau inversion recovery (STIR). AIS assessments were done initial examination and 1yr follow-up. Outcome measure below were assessed by MRI. **Outcome Measures:** Length of edema (LOE); intramedullary hemorrhage; AIS	outcome (i.e., no improvement in AIS). 2. There was no significant difference in intramedullary hemorrhage when comparing individuals who had AIS improvement and those who did not (p>0.05).
Matsushita et al., (2017) Japan Observational N=102	**Population**: SCI (n=102): Mean age=62.36yr (range=16-86); Gender: males=88, females=14; Level of injury: C=102; Time since injury=<72h for all AIS scale: A=32, B=15, C=42, D=13. **Intervention:** Individuals presenting with acute cervical SCI were included in the study. Magnetic resonance imaging (MRI) was performed using a 1.5T system with sagittal T2-weighted images (fast-recovery fast spin echo, echo train length=15, receiver bandwidth=150Hz/Px, matrix=384 X 229, section thickness=3mm, field of view=24cm). American Spinal Injury Association motor score (AMS) and modified Frankel D grade were assessed at admission and discharge. **Outcome Measures:** Increased intramedullary signal intensity (ISI); American Spinal Injury Association score (AMS); Frankel D score.	1. There was a significant negative correlation between ISI and AMS at both admission (r=-0.3766, p<0.001) and discharge (r=-0.4240, p<0.001) for individuals admitted within 1 day of SCI. 2. There was also a significant negative correlation between ISI and AMS at both admission (r=-0.6840, p<0.001) and discharge (r=-0.5293, p<0.01) for individuals admitted 2-3 days of SCI. 3. Receiver operating characteristic curve analysis determined an optimal ISI cut-off of 45mm for high versus low Frankel D score (i.e., not walking versus walking, respectively) in individuals who were admitted 2-3 days after SCI. With this cut-off, there was a significant positive correlation between ISI and being able to walk (p<0.001).
Song et al., (2016) Korea Observational N=102	**Population**: Complete SCI (n=10): Mean age=55.4yr (range=23-79); Gender: males=8, females=2; Level of injury: C=10; Time since injury=<12hr for all; AIS scale: A=10. Incomplete SCI (n=75): Mean age=57.2yr (range=28-87); Gender: males=65, females=10; Level of injury: C=75; Time since injury=<12hr for all; AIS scale: B=NR, C=NR, D=NR. Neurologically intact (n=17): Mean age=54.3yr (range=24-71); Gender: males=14, females=4; Level of injury: C=17; Time since injury=<12hr for all; AIS scale: E=17.	1. There was no significant difference in MSCC across the three groups (p=0.085). 2. Complete SCI showed significantly higher MCC compared to the other two groups (p<0.001). 3. Intramedullary hemorrhage and edema had significantly greater incidence in complete SCI compared to incomplete SCI and neurologically intact individuals (p<0.001).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Intervention: Medical records of individuals who underwent magnetic resonance imaging (MRI) scans for suspected spinal cord injury were assessed. **Outcome Measures:** Maximum spinal canal compression (MSCC); maximum cord compression (MCC); intramedullary lesion length (IMLL); intramedullary hemorrhage; spinal cord edema.	
Zohrabian et al., (2016) USA Observational N=108	**Population**: SCI (n=108): Mean age=48.9±20.9yr; Gender: NR; Level of injury: C=108, L=16; Time since injury=<72hr for all; AIS scale: NR. **Intervention:** Individuals suspected of SCI underwent neurological examination and diagnostic-quality magnetic resonance imaging (MRI) of the cervical spine. **Outcome Measures:** upper and lower boundaries of edema; lesion epicenter; upper and lower boundaries of cord hemorrhage; neurological level of injury (NLI).	1. All outcome measures showed statistically significant positive correlations with NLI. 2. Upper (r=0.72, p<0.01) and lower (r=0.61, p<0.01) boundaries of hemorrhage had the strongest correlation with NLI. 3. Bland-Altman analysis demonstrated that upper boundary of cord hemorrhage demonstrated the best agreement with NLI (p<0.01).
Schroeder et al., (2016) USA Observational N=75	**Population:** *Increased T2 signal (n=32):* Mean age: 57.1yr; Gender: males=19, females=13; Injury etiology: fall=24, motor vehicle accident=6, diving=; 2 Level of severity: mean Glasgow coma scale=15.0, mean injury severity score=22.2. *No increase in T2 signal (n=43):* Mean age: 57.3yr; Gender: males=31, females=12; Injury etiology: fall=31, motor vehicle accident=8, diving=2, sports=1, other=1; Level of severity: mean Glasgow coma scale=15.0, mean injury severity score=16.8. **Intervention:** Individuals with central cord syndrome were stratified based on presence of signal intensity on magnetic resonance imaging (MRI). Physician progress notes were reviewed for outcomes 1 wk post-injury. **Outcome Measures:** American Spinal Injury Association (ASIA) Motor Score (AMS), Surgery, Severity of injury.	1. Individuals in the increased signal group had more severe neurological injury on AMS at admission (p=0.01). 2. Throughout the wk, individuals with increased signal intensity maintained stable AMS whereas individuals without increased signal intensity on MRI declined within the first wk (p=0.07). 3. Individuals with increased signal intensity tended to experience less severe mechanism of injury through less major (p=0.09) and minor (p=0.15) injuries. 4. Incidence of surgical treatment and decompression was similar between both groups (p=0.99, p=0.10). 5. Individuals with increased signal intensity on MRI spent longer time in the ICU (p=0.001), but there was no difference in length of stay (p=0.22). 6. There was no significant relationship of age, sex, injury severity score, stenosis, or surgery with AMS (p>0.05).
Mabray et al., (2016) USA Observational N=25	**Population**: SCI (n=25): Mean age=38.32±15.74yr; Gender: males=17, females=8; Level of injury: T=24, without detectable injury=1; Mean time since injury=14.68±18.56hr; AIS at admission: A=11, B=2, C=, D=6, E=5. **Intervention:** This retrospective cohort study examined individuals who	1. Sagittal grade (rho=-0.83, p<0.001), LEI (rho=-0.83, p<0.001), and BASIC (rho =-0.93, p<0.001) showed significant negative correlations with AIS at discharge. There were no significant correlations between AIS score at

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	presented with acute thoracic or thoracolumbar SCI. MRI was performed at initial diagnosis using a 1.5T system. Images included sagittal T1 (slice thickness=3 mm, time to repetition/time to echo (TR/TE)=520-630/9-15ms, echo train length (ETL)=3, field of view (FOV)=30 cm2, acquisition matrix=512 X 512), sagittal T2 (slice thickness=3mm, TR/TE=3100-4000/105-120ms, ETL=19-21, FOV=30cm2, acquisition matrix=512 X 512), and axial T2 sequences (slice thickness=4 mm, TR/TE=4000-4800/102-120 ms, ETL=25, FOV=18 cm, acquisition matrix=512 X 512). AIS was assessed upon admission and at discharge. Outcome measures below were assessed by MRI. **Outcome Measures:** Brain and Spinal Cord Injury Center (BASIC) grade; Maximum canal compromise (MCC); Maximum spinal cord compression (MSCC); greatest longitudinal extent of injury (LEI); sagittal grade.	discharge and both MCC and MSCC ($p>0.05$). 2. In a multi-variable optimal scaled regression model, BASIC was the only statistically significant predictor of AIS at discharge ($p=0.001$).
Wang et al., (2016) China Observational N=35	**Population**: SCI (n=35): Mean age=57.2yr (range=42-69); Gender: males=21, females=14; Level of injury: C=35; Time since injury=NR; AIS scale: NR. **Intervention:** Imaging was performed on a 3.0T dual gradient superconductor MR with a gradient strength of 40mT/m and switching rate of 150mT/ms^{-1}. Sagittal flair-T_1W_1 (repetition time/echo time(TR/TE)=3200/116.8ms, section thickness=3mm, interlamellar spacing=1mm, field of view (FOW)=24X24 mm, image matrix=320X224, number of signals averaged (NEX)=2), sagittal FRFSE-T_2W_1 (TR/TE=2698/25.8ms, section thickness=3 mm, interlamellar spacing=1mm, FOV=240X240, image matrix=320X224, NEX=2), and axial FRFSE-T_2W_1 (TR/TE=3200/121ms, section thickness=4mm, interlamellar spacing=0.5mm, bandwidth=41.7kHz, FOV=180X180mm, image matrix=288X224, NEX=4) sequences were acquired for all individuals. MRI grading was performed by two radiologists; Grade 1, 2, and 3 constituted no static compression on spinal cord (no abnormal signals on sagittal T_1W_1 and T_2W_1), compression on spinal cord (normal sagittal T_1W_1 + increased signal intensity (ISI) on sagittal	1. There were no significant correlations between MRI and motor score, sensory score, or AIS before and after surgery ($p>0.05$).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	T_2W_1), and obvious compression on spinal cord (Low signal intensity on T_1W_1 + ISI on T_2W_1, respectively. Outcome measures were evaluated before surgery and 1 yr after surgery. **Outcome Measures:** Motor score; sensory score; American Spinal Injury Association index score (AIS).	
Wilson et al., (2012) Canada Case Series N=376	**Population:** *SCI (n=736):* Mean age=43.2yr; Gender: males=294, females=82; Level of severity: AIS A=136, AIS B=63, AIS C=58, AIS D=119; Mean time since injury=76.1hr. **Intervention:** Individuals received MRI following traumatic SCI. Outcomes were assessed at baseline and 1yr follow-up. **Outcome Measures:** MRI signal, American Spinal Injury Association Impairment Scale (AIS), American Spinal Injury Association Motor Scale (AMS), Functional Independence Measure (FIM).	1. MRI signal characteristics consistent with spinal cord edema or hemorrhage predicted worse functional outcome. 2. Parameters for predicting FIM motor score at 1yr (b=50.28) were MRI signal (m=4.83, p=0.19), AIS grade (m=12.47, p<0.01), AMS score (m=9.17, p<0.01), and age (m=-0.33, p<0.01). 3. Parameters for predicting FIM score at 1yr (b=-2.93) were MRI signal (m=-0.29, OR=0.75, p=0.54), AIS grade (m=1.36, OR=3.90, p<0.01), AMS score (m=1.35, OR=3.86, p<0.01), and age (m=-0.03, OR=0.97, p<0.01).
Miyanji et al., (2007) Canada Observational N=100	**Population**: SCI (n=100): Mean age=45yr (range=17-96); Gender: males=79, females=21; Level of injury: C=100; Median time since injury=24hr; AIS scale: A=26, B-D=51, E=22, Unknown=1. **Intervention:** Individuals with SCI were recruited as participants for this prospective study. Comparisons were made among injury severity American Spinal Injury Association (ASIA) A, B-D, and E. All individuals underwent MRI. Neurological assessment was done at baseline (time of MRI) and last clinical visit. **Outcome Measures:** Maximal canal compromise (MCC); maximum spinal cord compression (MSCC); lesion length; American Spinal Injury Association (ASIA) motor score; presence of: intramedullary hemorrhage, edema, cord swelling (focal widening of cord).	1. Frequency of intramedullary hemorrhage, edema, and cord swelling were more common in ASIA A versus ASIA B-D (p<0.001). Moreover, they were directly correlated with SCI severity (p<0.001). 2. MCC and MSCC were more substantial in ASIA A compared to ASIA B-D (r^2=0.222, p=0.005; r^2=0.171, p=0.002, respectively). 3. Lesion length was significantly greater in ASIA A compared to ASIA B-D (r^2=0.343, p=0.005). 4. Step-wise multivariate regression found that the best model for predicting baseline ASIA included MCC, MSCC, and cord swelling. 5. Step-wise multivariate regression adjusted for baseline ASIA motor score found that only intramedullary hemorrhage and cord swelling were predictive of follow-up ASIA motor score.
Boldin et al., (2006) Austria Observational N=29	**Population**: SCI with Hemorrhage (n=17): Mean age=35.4±12.3yr; Gender: NR; Level of injury: C=17; Median time since injury=10(range=5-12)d; AIS scale: A=8, B=8, C=1. SCI without Hemorrhage (n=12): Mean age=55±19.3yr; Gender: NR; Level of injury: C=12; Median time since	1. Participants with spinal cord hemorrhage had significantly longer edema (p=0.002) and more severe ASIA scores (p<0.001). 2. Participants with complete motor SCI were significantly more likely to have indications of hemorrhage compared to those with incomplete lesions (p<0.001).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	injury=6(range=5-11)d; AIS scale: B=3, C=7, D=2. **Intervention:** Participants with closed cervical SCI were recruited for this prospective study. MRI was performed on all participants. Neurological impairment was assessed at time of MRI and at median follow up of 35 mo (range=24-65). **Outcome Measures:** hemorrhage length; edema length; American Spinal Injury Association (ASIA) classification; recovery rate (RR) of the following: motor score; sensory score; pin prick score.	3. Baseline motor, pin prick, and sensory scores were significantly lower in the presence of hemorrhage (p=0.006; p=0.001; p=0.001, respectively). 4. RR of pin prick and sensory scores were significantly lower in participants with hemorrhage (p=0.008; p=0.011, respectively). There was no significant difference in RR of motor score between hemorrhage versus no hemorrhage (p>0.05). 5. ANOVA revealed statistically different edema lengths among the levels of ASIA score (p=0.001). ASIA A was statistically longer than ASIA C, D, and E. There was no difference in edema length when comparing ASIA A to B (p>0.05). 6. Hemorrhage length was longer in complete SCI (ASIA A) compared to incomplete SCI (ASIA B-E) (p=0.002). 7. Logistics regression revealed that length of edema was the only predictive measure for all participants (hemorrhage and no hemorrhage). Each mm increase in edema resulted in a 1.15 (1.03-1.29) increased rate of retaining a complete SCI (p=0.022).
Shepard & Bracken (1999) USA Observational N=191	**Population**: SCI (n=191): Mean age=NR; Gender: males=162, females=29; Level of injury: NR; Time since injury: ≤9hr=99, >9hr=92; Injury severity: Complete=75, Incomplete=87, Normal=29. **Intervention:** This was a retrospective review of participants from another study. Participants who received MRI within 72hr of injury were included in this study. Participants were assessed neurologically based on responses to pin prick, light touch, and motor function at baseline and at 6wk follow-up. **Outcome Measures:** Positive MRI response of: hemorrhage, contusion, edema; neurological assessment (see intervention).	1. Participants characterized with a complete SCI based on radiologic and neurologic examination were significantly more likely to have spinal cord hemorrhage compared to those classified as neurologically normal on motor function but with impaired sensation (p=0.01). 2. There was no significant difference in the presence of contusion and edema when comparing complete SCI to incomplete SCI (p>0.05). 3. Participants whose MRI imaging indicates hemorrhage or contusion are significantly more likely to have lower motor, pin, and touch scores at baseline (p<0.05). However, there are no significant differences for participants with edema (p>0.05). 4. There was no statistical difference in recovery of pin, motor, and touch scores at 6wk when comparing participants who have hemorrhage, contusion, or edema (p>0.05).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
		5. A logistic regression adjusting for neurological examination scores at baseline found that there were no significant increased odds for a complete spinal cord injury in the presence of hemorrhage, contusion or edema (p>0.05). 8. There was no significant difference in motor function and sensory recovery at 6wk when comparing participants with hemorrhage, contusion, and edema (p>0.05).
Selden et al., (1999) USA Observational N=55	**Population:** *Cervical Myelopathy (n=55):* Mean age: 29.2yr; Gender: males=36, females=19; Injury etiology: motor vehicle accident=32, diving accident=11, fall=9, other=3; Level of injury range: C2-T1; Level of severity: Frankel grade A=32, B=9, C=8, D=6; Time since injury range: <17hr. **Intervention:** Individuals with traumatic cervical myelopathy underwent magnetic resonance imaging (MRI) of the spine. Outcomes were assessed at admission and at the most recent follow-up visit an average of 18.5mo. **Outcome Measures:** Frankel Grade, Medical Research Council (MRC) motor grades, Spinal cord length and diameter, Presence of hematoma, edema, and hemorrhage.	1. Abnormal T2-hyperintensity MRI images representing edema were present in 54 of 55 individuals. 2. Rostrocaudal length of signal changes, but not spinal cord swelling or maximal diameter, was significantly correlated with poor neurological function on Frankel Grades at admission (p=0.001). 3. Abnormal T2-hypointensity representing intra-axial hemorrhage was present in 22 individuals (40%), all which had poor Frankel Grade A or B injuries on admission and this was significantly different than those without hypointense signals (p=0.001). 4. Rostrocaudal length of hemorrhage signal changes were significantly correlated with worse Frankel Grades after MRI (p=0.049), but not at follow-up. 5. Rostrocaudal length of edema, but not maximal diameter or length, was significantly correlated with worse Frankel Grade at the follow-up (p=0.036). 6. The strongest predictor of neurological outcome was Frankel Grade at presentation (p<0.001). 7. Hemorrhage on MRI scans were correlated with motor-complete injury at admission and associated with poor long term Frankel Grade scores. 8. There was a decrease in Frankel Grade at admission to follow-up for rostrocaudal length of hematoma (p=0.028), compression via extra-axial hematoma (p=0.077) and rostrocaudal length of edema (p=0.071). 9. There was a significant negative correlation between length of spinal edema on MRI and total motor score improvements on MRC (p=0.041).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Flanders et al., (1996) USA Case Series $N_{Initial}$=118 N_{Final}=104	**Population:** *SCI (n=104):* Mean age: 34 yr; Gender: males=91, females=13; Injury etiology: motor vehicle accident (n=49), fall (n=27), sport (n=8), other (n=20); Level of injury: cervical; Level of severity: AIS A=43, B=23, C=28, D=10; Time since injury: <1wk. **Intervention:** Individuals with cervical SCI who underwent MRI were retrospectively analyzed for prediction of motor recovery. **Outcome Measures:** American Spinal Injury Association Motor Score.	1. Individuals with spinal cord hemorrhage had significantly worse upper and lower motor scores at the time of injury and at 12mo (p<0.001). 2. Individuals without spinal cord hemorrhage had little recovery of lower extremity function. 3. Upper extremity function improved in all individuals (p<0.001); however, individuals without hemorrhage showed the largest improvements.
Takahashi et al., (1993) Japan Observational N=49	**Population:** *SCI (n=29):* Mean age=47.7 yr; Gender: males=42, females=7. **Intervention:** Individuals received MRI within 1wk of SCI. Some individuals (n=25) received follow-up MRI. All individuals were classified based on MRI pattern: Type 0 for T1/T2WI isointensity, Type I for T1WI isointensity and T2WI hyperintensity, Type II for T1WI hypointensity and T2WI hyperintensity, and Type III for T1WI hyperintensity. **Outcome Measures:** MRI pattern, Signal intensity, Cord compression, Recovery.	1. Individuals presented with compression of varying degrees: none (n=5), minimal (n=7), moderate (n=22), or severe (n=15). Most common causes were subluxation (n=17) and fracture (n=11). 2. Individuals initially presented with the following MRI patterns: Type 0 (n=13), Type I (n=30), Type II (n=1), and Type III (n=5). They later presented with the following patterns: Type 0 (n=4), Type I (n=8), and Type II (n=13). 3. Individuals showed recovery of varying degrees: none (n=22), some recovery (n=16), or complete recovery (n=11). 4. Initial MRI pattern was associated with recovery as follows: Type 0 had 92%, Type I had 53%, and both Types II and III had 0%. 5. Subsequent MRI pattern was associated with recovery as follows: Type 0 had 75%, Type I had 63%, and Type II had 69%. 6. Initial T2WI high intensity area was associated with recovery as follows: <1 vertebral body was 100%, 1-2 vertebral bodies was 88%, and >2 vertebral bodies was 20%. 7. Subsequent T2WI high intensity area was associated with recovery as follows: <1 vertebral body was 100%, 1-2 vertebral bodies was 67%, and >2 vertebral bodies was 0%. 8. Compression was associated with recovery as follows: severe had 33%, moderate had 55%, minimal had 71%, and none had 100%.
Schaefer et al., (1992) USA Observational N=57	**Population**: Group 1 (n=21): Mean age=27.2yr; Gender: NR; Level of injury: C=21; Time since injury=NR; Mean American Spinal Injury Association (ASIA) motor score: 12.1.	1. Group 1 had no statistically significant improvement in ASIA motor scores at follow-up (p>0.05).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Group 2 (n=17): Mean age=43.5yr; Gender: NR; Level of injury: C=17; Time since injury=NR; Mean ASIA motor score=28.6. Group 3 (n=19): Mean age=38.4yr; Gender: NR; Level of injury: C=19; Time since injury=NR; Mean ASIA motor score=38.3. **Intervention:** Individuals with closed cervical spinal cord injuries were recruited as participants for this study. All participants underwent MRI. Neurological assessment (ASIA motor score) was assessment at baseline (time of MRI) and at follow-up. Participants were divided into three groups based on MRI findings. Group 1 consisting of patterns characteristic of intramedullary hematoma; group 2 had intramedullary edema over more than one spinal region without hemorrhage; group 3 had intramedullary edema restricted to one spinal segment or less. **Outcome Measures:** ASIA motor score; Median percent recovery.	2. Group 2 had significantly greater median recovery score compared to group 1 ($p<0.02$). 3. Group 3 had significantly greater median recovery score compared to both group 1 and 2 ($p<-.001$; $p<0.01$, respectively). 4. Baseline median ASIA motor score was significantly greater than group 1 ($p<0.001$). However, there was no difference in baseline ASIA motor score when comparing group 3 to 2 ($p>0.05$).

Discussion

MRI is the imaging modality of choice in SCI due to its high psychometric and prognostic value. Yasin et al., show that MRI is a highly sensitive (97%) and accurate technique (95%). MRI demonstrated high psychometrics in SCI with or without edema and hemorrhage, except when trying to asses for combination of edema and hemorrhage without contrast as Ghasemi et al., (2015) demonstrate. Karpova et al., (2013) demonstrate high intraobserver correlation for quantitative MRI measurements related to the spine.

MRI also showed strong prognostic value in predicting the initial injury and course of injury based on signal intensity. Selden et al., (1999) showed that hemorrhage on MRI scans were correlated with motor-complete injury at admission and associated with poor long-term Frankel Grade scores. Initial MRI pattern was associated with recovery. MRI signal characteristics consistent with spinal cord edema or hemorrhage predicted worse functional outcome as Wilson et al., demonstrate. The study conducted by Flanders et al., (1996) found that individuals with spinal cord hemorrhage had significantly worse upper and lower motor scores at the time of injury and at 12 months. Miyanji et al., (2007) demonstrate that the frequency of intramedullary hemorrhage, edema, and cord swelling were more common in American Spinal Injury Association A versus American Spinal Injury Association B-D. Moreover, they were directly correlated with SCI severity. Only one study by Wang et al., (2016) showed no significant correlation between MRI findings and motor, sensory or American Spinal Injury Association score.

Conclusion

There is level 4 evidence (from one case series study; (Karpova et al., 2013), and two observational studies; (Ghasemi et al., 2015, Yasin et al., 2017) that MRI has strong inter-observer correlation, sensitivity, specificity, predictive value, and diagnostic accuracy in detecting and evaluating SCI in individuals.

There is level 5 evidence (from one case series study; (Schroeder et al., 2016) that the incidence of surgical treatment and spinal decompression is not significantly different between individuals based on the presence of signal intensity on an MRI.

There is conflicting level 3 evidence (from one cohort study; (Mabray et al., 2016), one case control study; (Seif et al., 2018), two case series; (Flanders et al., 1996), (Wilson et al., 2012), and six observational studies; (Aarabi et al., 2017, Schaefer et al., 1992, Selden et al., 1999, Song et al., 2016, Takahashi et al., 1993, Zohrabian et al., 2016) and level 5 evidence (from one observational study (Wang et al., 2016) that MRI is effective in determining microstructural measurements and can reliably predict AIS classification, motor score and status and progression of injury in individuals with SCI and controls.

There is level 5 evidence (from one cohort study; (Martinez-Perez et al., 2017) that early MRI has prognostic value in its ability to evaluate ligamentous injury and edema which are predictors of poor neurologic outcome.

There is level 5 evidence (from one observational study; (Miyanji et al., 2007) that MRI can be used to detect hemorrhage, edema, and cord swelling in individuals with SCI. A greater number of positive detections were significantly associated with increased SCI severity and American Spinal Injury Association classification.

There is level 5 evidence (from two observational studies; (Boldin et al., 2006; Shepard & Bracken 1999) that MRI may be used to predict complete SCI given the detection of hemorrhage and edema in individuals with SCI.

There is level 5 evidence (from one observational study; (Dalkilic et al., 2018) that MRI could be used to assess hematoma length and predict AIS classification at baseline.

There is level 5 evidence (from one observational study; (Matsushita et al., 2017) that MRI is effective in detecting spinal microstructures which can be used to effectively predict American Spinal Injury Association motor scores, and Frankel D scores in individuals with SCI.

MRI is an effective diagnostic tool to assess damage to microstructures within the spinal cord as well as detecting other indications of damage such as hemorrhage and edemas.

MRI may be reliably used to predict an individual's injury severity, American Spinal Injury Association score, motor score, AIS, and neurologic outcome given an SCI.

5.1 Spinal Cord Injury Without Radiographic Abnormality

In some instances, individuals with an SCI may not present with any radiographic abnormalities. Although this is considered less common it is still worth noting. Spinal cord injury without radiological abnormality accounts for approximately 10% of SCIs and can be an indication for MRI. The few studies which have found no radiographic abnormalities are presented in Table 2 below.

Table 2 The use of MRI in Individuals Without Radiographic Abnormalities

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Martinez-Perez et al., (2017) Canada Observational N=48	**Population**: Spinal Cord Injury Without Radiographic Abnormality (SCIWORA) (n=48): Mean age=54±18.3yr; Gender: males=40, females=8; Level of injury: C=48; Time since injury: ≤72hr; American Spinal Injury Association (ASIA): A=2, B=5, C=15, D=26. **Intervention:** Individuals who were admitted to hospital with cervical SCI, received MRI imaging within 72 hr, diagnosed with SCIWORA, and had at least 1 yr of follow-up were included in this retrospective study. MRI was performed using a 1.5T magnet with axial T1-weighted images, T2-weighted images, and gradient echo (GRE); and sagittal T1-weighted images, T2-weighted images, and short TI inversion recovery sequences. Neurological status was assessed using the ASIA impairment scale at baseline and 1-yr follow-up. Neurological improvement was defined as the improvement of at least 1 point on the ASIA Impairment Scale. **Outcome Measures**: Disk integrity; swelling; intramedullary hematoma; extramedullary hematoma; edema; cervical canal stenosis; lesion length; maximal canal; maximal spinal cord compromise.	1. There were no significant associations with any of the outcome measures and neurological improvement, with the exception of MRI lesion length. In particular, shorter lesions on MRI were associated with neurological improvement (p=0.01).
Ouchida et al., (2016) Japan Observational N=68	**Population**: Spinal Cord Injury Without Radiographic Abnormality (SCIWORA) (n=68): Mean age=62(16-93)yr; Gender: males=52, females=16; Level of injury: C=68; Time since injury: ≤4hr; AIS: A=6, B=7, C=24, D=31. **Intervention:** Individuals diagnosed with SCIWORA were included in this study. T2-weighted sagittal images were acquired using a 1.5T MRI for all individuals. Additionally, individuals underwent a delayed MRI 2 weeks after injury. Outcome measures were assessed at diagnosis and 1-yr follow-up. **Outcome Measures**: Increased signal intensity (ISI) grade and range; prevertebral hyper-intensity range (PVH);	1. There was no significant correlation between JOA and ISI grade and range at admission (p=0.11, r=-0.19; p=0.10, r=-0.20, respectively). However, there was a significant correlation between JOA and PVH at admission (p<0.001, r=-0.55). 2. There were significant correlations between JOA and ISI grade and range, as well as PVH on delayed MRI imaging (p<0.001, r=-0.49; p<0.05, r=-0.24; p<0.001, r=-0.46, respectively).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Neurological status: Japanese Orthopaedic Association scoring system (JOA score).	

Discussion

Only two studies meeting our inclusion criteria examined individuals diagnosed with SCI without radiographic abnormality (Martinez-Perez et al., 2017, Ouchida et al., 2016). Martinez-Perez et al., (2017) assessed individuals who had normal CT scans and did not find any significant associations between physiological outcome and neurological improvement, except for in lesion length as seen on MRI. In this case, shorter lesion length was significantly associated with neurological improvement. Ouchida et al., (2016) found that MRI signal intensity was not significantly associated with the Japanese Orthopaedic Association scoring system, but prevertebral hyper-intensity range was. The first study suggests that an early MRI may pick up traumatic lesions in cases where CT has been negative. These studies also loosely suggest that MRI is less useful as a prognostic indicator of outcome and status in individuals diagnosed with SCI without radiographic abnormality compared to those with SCI who demonstrate radiographic abnormalities.

Conclusions

There is level 5 evidence (*from one observational study; (*Martinez-Perez et al., 2017) that an early MRI may have prognostic value in individuals with SCI without CT evidence of trauma.

There is level 5 evidence (from an observational study (Ouchida et al., 2016) that MRI may not be an effective diagnostic or prognostic indicator of injury in individuals diagnosed with SCI without radiographic abnormality.

For individuals with SCI without radiographic abnormality MRI may not be useful in determining current injury severity or predicting outcome following injury.

6.0 Diffusion Tensor Imaging (DTI)

DTI is a novel imaging technique, which is an extension of diffusion weighted imaging. It has the potential to identify intact nerve fibre tracts and has been used to image the brain for a variety of conditions. It is currented used mainly as a research tool when imaging the spine and has not been widely implemented in mainstream clinical practice. However, early studies have shown that it holds considerable promise in predicting the severity of spinal cord injury.

Table 3 Use of Diffusion Tensor Imaging in Those With SCI

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Choe et al., (2017) USA Case Control $N_{Initial}$=29 N_{Final}=28	**Population**: SCI (n=18): Mean age=46.72±14.47yr; Gender: males=14, females=4; Level of injury: C=18; Time since injury=9.83±11.45yr; AIS: A=3, B=2, C=6, D=7. Healthy Controls (n=10): Mean age=33yr (range=21-49); Gender: males=6, females=4. **Intervention:** Diffusion fiber tractography was performed on all participants with a Philips 3-T scanner using a 16-channel neurovascular coil. Images were acquired using multi-slice pulsed gradient spin echo sequence, b=0 and 500s/mm2, 16 diffusion-weighted directions that sample a prolate tensor, TR/TE=6300/63ms, SENSE factor=2, 96X96X40 volume matrix, 1.5X1.5X3mm3 resolution (axial sections of 3mm thickness; zero-filled to 0.57X0.57X3mm3), and matrix size=256X256X40. The entire length of the spinal cord serves as the field of view. Regions of interest included the following regions relative to injury (RRI); epicenter RRI (ERRI); superior RRI (SRRI) defined as the region located above the superior edge of the ERRI up to approximately one vertebral level; inferior RRI (IRRI) defined as the region below the inferior edge of the ERRI to the length of approximately one vertebral level. Diffusion Tensor Imaging (DTI) indices were also averaged over all RRI to create an all-level region (AL) value for each index. DTI indices were measured for each spinal cord column region (left, right, dorsal, and ventral columns) within each RRI (ERRI, SRRI, IRRI). The International Standard of Neurological Classification for SCI (ISNCSCI) total score was determined for each SCI participant by summing the total motor score (upper and lower motor extremity scores) and total sensory score (left and right light touch). **Outcome Measures**: DTI indices: Fractional Anisotropy (FA); axial diffusivity (AD); radial diffusivity.	1. All DTI indices of different RRIs differed significantly ($p<0.05$). 2. DTI indices did not differ between spinal cord columns (i.e., left, right, dorsal, and ventral columns) ($p>0.05$). 3. There were no significant relationships between DTI indices and total ISNCSCI scores from different spinal cord columns ($p>0.05$). 4. For the AL region, individuals with SCI had significantly decreased and increased FA and RD compared to normal controls, respectively ($p<0.05$). There was no significant difference in AD in the AL region ($p>0.05$).
D'Souza et al., (2017) India Case Control N=50	**Population**: SCI (n=20): Mean age=35.95±10.86yr; Gender: males=14, females=6; Level of injury: C=20; Time since injury=≤7d; AIS: NR. Healthy Controls (n=30): Mean age=35.90±10.13yr; Gender: males=20, females=10. **Intervention:** All participants underwent Diffusion Tensor Imaging (DTI) using a	1. At the level of injury, FA was significantly lower for SCI when compared to healthy controls ($p<0.001$). However, MD was significantly higher for SCI at the level of injury when compared to healthy controls ($p<0.001$). 2. There were no significant differences in MD and FA above and

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	single shot echo planar imaging (EPI) sequence (b-value=0,700 s/mm^2) using 20 diffusion encoding directions. Images were acquired using Sagittal T1: repetition time/echo time(TR/TE)=450/9.5ms; Sagittal T2:TR/TE–3630/104ms; Axial T1: TR/TE–450/9.6ms and Axial T2: TR/TE-500/15 ms. Images were acquired in the axial plane with an image matrix of 128X128, 5mm slice thickness with no inter-slice gap, and a 280X280mm field of view. SCI participants were reassessed clinically 1-2 mo after imaging. **Outcome Measures**: Mean diffusivity (MD); fractional anisotropy (FA); Frankel grading system score (FGS).	below the injury when comparing SCI to healthy controls (p>0.05). 3. There was a statistically significant positive correlation between FA values at the level of injury and FGS (r=0.86, p<0.001). In contrast, there was no significant correlation between MD at the level of injury and FGS (p>0.05). 4. Qualitative analysis of the cord on tractography revealed that 12 cases suggested disruption in cord integrity.
Shanmuganathan et al., (2017) USA Case Control $N_{Initial}$=45 N_{Final}=31	**Population**: SCI (n=16): Median age=53(range=20-79)yr; Gender: males=13, females=3; Level of injury: C=16; Time since injury=≤5d; The International Standard of Neurological Classification for SCI (ISNCSCI) at discharge: A=5, B=2, C=3, D=6. Healthy Controls (n=15): Median age=46(range=26-69)yr; Gender: males=12, females=3. **Intervention:** All participants underwent Diffusion Tensor Imaging (DTI) with a 1.5-T Avanto scanner with a 12-channel head and four-channel neck array using single-shot echo planar imaging (EPI) sequence at a TE/TR of 87/2800 msec. Sagittal T2 (echo time/ repetition time (TE/TR)=109/4000 ms), fluid attenuation inversion recovery (FLAIR) (TE/TR=102/8000 msec, echo train length (ETL)=13), and axial T2 and T2*, three-dimensional [3D] susceptibility weighted imaging (SWI) (TE/TR: 16/30msec, flip angle: 20 degrees) images were included. For SCI, Regions of interest included areas of edema (confirmed by T2 and STIR sequences) and hemorrhage (confirmed by SWI and T2* sequences). For healthy controls, regions of interest included upper (lower brainstem-lower C2), mid (upper C3-lower C5), and lower (upper C6-lower T1) regions. The International Standard of Neurological Classification for SCI (ISNCSCI) was assessed at discharge and at 1-yr follow-up. **Outcome Measures**: ISNCSCI motor score; Spinal cord independence measure III (SCIM); Radial diffusivity (RD); axial diffusivity (AD);	1. FA was significantly lower in SCI when compared to lower (p<0.001), mid (p<0.001), and upper (p<0.001) regions in healthy controls. 2. AD was significantly lower in SCI when compared to lower (p<0.001), mid (p<0.001), and upper (p<0.001) regions in healthy controls. 3. RD was significantly higher in SCI when compared to mid (p<0.001) and upper (p<0.001) regions of healthy controls. There was no significant difference in RD when comparing SCI to the lower region of healthy control (p>0.05). 4. There was no significant difference in MD when comparing SCI to all regions of healthy controls (p>0.05). 5. Pearson correlations revealed significant correlations between MD and the presence of hemorrhagic contusions (r=0.42, p<0.05), ISNCSCI motor score (r=0.66, p<0.05), and SCIM (r=0.64, p<0.05). 6. There was a significant correlation between FA and age (r=-0.55, p<0.05). 7. AD was significantly correlated with presence of hemorrhagic contusion (r=0.42, p<0.05), ISNCSCI motor score (r=0.76, p<0.001), and SCIM (r=0.77, p<0.01). 8. RD was significantly correlated with age (r=0.5, p<0.05) and ISNCSCI motor score (r=0.53, p<0.05). 9. Step-wise regression revealed MD (r^2=0.89, p=0.002), AD (r^2=0.0.93, p<0.001), and RD (r^2=0.86, p=0.014) were significant predictors of ISNCSCI motor score at the 1-

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	mean diffusivity (MD); fractional anisotropy (FA).	year follow-up for participants with or without hemorrhage spinal cord injury. FA was not a significant predictor in the model (p>0.05). 10. MD, AD, FA, and RD were not significant predictors of SCIM at 1-year follow-up for both hemorrhagic and non-hemorrhagic spinal cord injury (p>0.05).
Wang et al., (2016) China Observational N=35	**Population**: SCI (n=35): Mean age=57.2yr (range=42-69); Gender: males=21, females=14; Level of injury: C=35; Time since injury=NR; AIS scale: NR. **Intervention:** Imaging was performed on a 3.0T dual gradient superconductor MR with a gradient strength of 40mT/m and switching rate of 150mT/ms^{-1}. Difusion Tensor Imaging (DTI) consisted of a single-shot spin-echo-planar sequence (b value=1000 s/mm^2, repetition time/echo time=8000/87.6ms, section thickness=4mm, interlamellar spacing=0mm, bandwidth=250 kHz, field of view=180X180mm, image matrix=130X128, number of signals averaged=2. DTI grading was performed by two radiologists; Grade 1, 2, and 3 constituted mixed signal in lesion area but complete and continuous fiber bundle, abnormal signal and disordered fiber bundle in local lesion, interrupted fiber bundle, respectively. Outcome measures were evaluated before surgery and 1 yr after surgery. **Outcome Measures:** Motor score; sensory score; American Spinal Injury Association (ASIA) index score (AIS).	1. There was a significant correlation between AIS and DTI grading before and after surgery (p<0.05, r=0.475; p<0.01, r=-0.529, respectively). 2. There was also a significant correlation between DTI grading and motor score, as well as sensory score after surgery (p=<0.01, r=0.492; p<0.05, r=0.476, respectively). 3. There were no significant correlations between DTI grading and motor score and sensory score before surgery (p>0.05).
Kim et al., (2015) Korea Case Control N=38	**Population**: SCI (n=17): Mean age=47.0±13.4yr; Gender: males=11, females=6; Level of injury: C=17; Time since injury=13.1±19.9mo; Etiology: Vertebral fracture=5, compressive myelopathy=3, degenerative myelopathy=1, transverse myelopathy=2, cervical myelopathy=1, spinal cord contusion=4, ossification of posterior longitudinal ligament=1; AIS: A=4, B=1, C=2, D=10. Healthy Controls (n=21): Mean age=38.5±15.7yr; Gender: males=13, females=8. **Intervention:** All participants were assessed with Diffusion Tensor Imging (DTI) using a Tim 3-Tesla MR scanner with a 12-channel head coil and 4-channel neck coil. Axial images had the	1. SCI had significantly lower FA in all three regions (lateral, dorsal, ventral) and all levels (at injury, above injury, below injury) compared to healthy controls (p<0.05). 2. SCI had significantly higher ADC in all three regions (lateral, dorsal, ventral) and at two levels (injury level and below injury) compared to healthy controls (p<0.05). However, there was no significant difference in ADC above the injury for all three regions (lateral, dorsal, ventral) (p>0.05). 3. Peak systolic vCSF was significantly higher in SCI at the injury level when compared to healthy controls (p<0.05).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	following parameters; repetition time/echo time (TR/TE)=5100/77ms; number of signals averaged (NEX)=10; b-value=0, 750s mm−2; diffusion direction=6; image matrix=140 X 36; field of view (FOV)=140X36 mm2; slice thickness=5 mm; total number of slices=17; voxel resolution=1.0X1.0X5mm3; bandwidth=916 Hz per pixel; and total acquisition time(TA)=6min and 2s. Sagittal T2-weighted images were acquired using a T2-weighted fast spin-echo (FSE) sequence. In the SCI participants, DTI indices were measured at the level of injury, above the injury (at least one vertebral segment above), and below the injury (at least one vertebral segment below). DTI indices of healthy controls were measured at C2-C3, C4-C5, and C6-C7 for comparison against above the injury, at the level of injury, and below the injury of SCI, respectively. DTI indices were assessed along the lateral, dorsal, and ventral regions of the spinal cord in all participants. **Outcome Measures**: AIS; American Spinal Injury Association (ASIA) motor and sensory scores; modified Barthel index score (MBI); Spinal cord independence measure III (SCIM); somatosensory evoked potentials (SEP) latency and amplitude; DTI indices: Intramedullary fractional anisotropy (FA), apparent diffusion coefficient (ADC); cerebrospinal fluid velocity (vCSF);	4. Peak diastolic cCSF was significantly lower in SCI below the injury when compared to healthy controls ($p<0.05$). 5. In SCI participants, FA was significantly correlated with systolic and diastolic vCSF above the injury and at the level of the injury ($p<0.05$). Systolic and diastolic vCSF at the injury and below the injury were significantly correlated with changes in FA at the injury level and above the injury ($p<0.05$) 6. There were no significant correlations between ADC and vCSF ($p>0.05$). 7. In SCI, there were significant negative correlations between both right and left ulnar nerve SEP latency and right lateral FA (r=-0.560, p=0.046; r=-0.676, p=0.041), left lateral FA (r=-0.676, p=0.011; r=-0.675, p=0.011), and dorsal FA (r=-0.641, p=0.018; r=-0.652, p=0.016). 8. There was also a significant negative correlation between the right tibial nerve SEP latency and dorsal FA (p=0.010), as well as the left tibial nerve and both left lateral FA (r=-0.632, p=0.021) and dorsal FA (r=-0.695, p=0.008). 9. There was a significant positive correlation between left tibial nerve SEP amplitude and ventral FA (r=0.585, p=0.036). 10. FA of the ventral area at the level of injury was significantly correlated with ASIA sensory score (r=0.687, p=0.009). 11. FA below the level of injury significantly correlated with AIS (r=-0.773, p=0.014) and SCIM (r=0.680, p=0.044). 12. There was no significant correlation between both FA and ADC and ASIA motor score or MBI ($p>0.05$).
Koskinen et al., (2013) Finland Case Control N=68	**Population:** *SCI group (n=28)*: Mean age: 59.9yr; Gender: males=22, females=6; Injury etiology: motor vehicle accident (n=10), fall (n=12), sports (n=3), assault (n=1), other (n=2); Level of injury: cervical=27, thoracic=1; Level of severity: AIS A=7, B=1, C=3, D=16, E=1; Mean time since injury: 13.1yr.	1. The FA values of the SCI were group were significantly lower than those of the CG group ($p<0.001$). 2. ADC and RD values of the SCI group were significantly higher than those in the CG group ($p<0.0001$ and $p<0.00001$, respectively). 3. In the SCI group, the FA values were positively correlated with the motor ($p<0.01$) and sensory ($p<0.001$) scores of ISNCSCI.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Healthy Control (CG) group (n=40): Mean age: 40.6yr; Gender: males=20, females=20. **Intervention:** Researchers aimed to quantify the association between diffusion tensor imaging (DTI) parameters in individuals with cervical traumatic SCI. **Outcome Measures:** Apparent Diffusion Coefficient (ADC), Fractional Anisotropy (FA), Radial Diffusivity (RD), International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI), Functional Independence Measure (FIM).	4. In the SCI group, the FA values were positively correlated with the motor subscale of FIM (p<0.01). 5. DTI revealed SCI pathology, which was undetectable using conventional MRI.
Ellingson et al., (2008b) USA Case Control N=8	**Population**: SCI (n=4): Mean age=42.25±14.04yr; Gender: NR; Level of injury: C=3, T=1; Time since injury=13±11.09yr; AIS: A=1, B=1, C=2. Healthy Controls (n=4): Mean age=29±4.85yr; Gender: NR **Intervention:** Diffusion Tensor Imaging (DTI) images were obtained for all participants using a head coil and a 1.5T scanner. Twelve axial slices throughout the upper cervical spine using a single-shot EPI/SE (dual spin echo) pulse sequence were acquired with repetition time/echo time (TR/TE)=6000/88.1ms, field of view (FOV)=200 mm, and number of signals averaged (NEX)=4 (T2-weighted image only) for each participant. Images were taken rostral to the injury site and in equivalent regions for SCI and healthy participants, respectively. Morphology analysis was done by FIS tissue classification. **Outcome Measures**: Fractional anisotropy (FA); longitudinal apparent diffusion coefficient (LADC); transverse apparent diffusion coefficient (TADC); mean diffusivity (MD); cross-sectional area (CA).	1. FIS images of SCI participants were less clear compared to healthy control vis-à-vis presence of distinct gray matter shape. Additionally, there seemed to be a changes in shape and decreases in size of the spinal cord in SCI comparted to controls. 2. SCI had significantly lower TADC, LADC, and MD in gray matter (p=0.008; p=0.033; p=0.007, respectively), white matter (p=0.002; p=0.005; p<0.001, respectively), as well as individual white matter regions including the dorsal funiculus (p=0.039; p<0.001; p<0.001, respectively), and lateral funiculi (pp<0.001; p=0.01; p<0.001, respectively). 3. There was no significant difference in TADC, LADC, and MD for cerebrospinal fluid (p>0.05). 4. SCI had significantly smaller whole cord and white matter tract cross-sectional area compared to controls (p=0.001; p<0.001, respectively). There was no significant difference in cross-sectional area of gray matter (p=0.109). 5. Frontal and sagittal diameters were significantly smaller in SCI (p<0.001; p=0.009, respectively), suggesting spinal cord atrophy.
Ellingson et al., (2008a) USA Case Control N=23	**Population**: SCI (n=10): Median age=37yr (range=25-67); Gender: NR; Level of injury: C=6, T=5; Time since injury=>4yr; Injury type: complete=4, incomplete=6. Healthy Controls (n=13): Median age=25yr (range=25-67); Gender: NR **Intervention:** Diffusion Tensor Imaging (DTI) images of the entire spinal cord (c1-L1) were obtained for all participants	1. Controls had higher whole cord FA compared to SCI, especially in white matter dense areas (p<0.001). 2. Subjects with complete SCI had significantly higher TADC and MD throughout the whole spinal cord compared to subjects with incomplete SCI (p=0.011; p=0.037, respectively). However, there was

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	using a CTL Spine Coil with anterior neck coil attachment. Images were acquired with TE/TR=96.3/6000ms, matrix size=128X128, number of signals averaged (NEX)=1, FOV=200mm, and a section thickness of 5mm with no intersection gap. Diffusion-weighted images (DWIs) were acquired with b=1500s/mm^2 in 25 equidistant directions. A single T2-weighted (T2WI) (b =0s/mm^2) was acquired for each section. **Outcome Measures**: Fractional anisotropy (FA); Transverse apparent diffusion coefficient (TADC); longitudinal apparent diffusion coefficient (LADC); mean diffusivity (MD).	no significant difference in LADC (p>0.05). 3. Subjects with lower cervical lesions showed significantly lower TADC and MD throughout the spinal cord compared with thoracic lesions (p=0.012; p=0.019, respectively). 4. TADC, LADC, and MD were significantly higher at the lesion in SCI compared to healthy controls (p<0.05 for all). 5. Completeness of injury and level of injury were not significant factors for changes in LADC, TADC, and MD in the cervical spinal cord (p>0.05). 6. There were no significant interactions between lesion level and vertebral level, as well as completeness of injury and vertebral level for TADC (p>0.05). However, FA was significantly lower in subjects with complete SCI compared to those with incomplete SCI (p<0.001). 7. Comparisons between SCI with upper cervical lesions and healthy controls revealed significantly lower LADC, TADC, and MD for SCI at C1, C2, and C3 (p<0.05).
Shanmuganathan et al., (2008) USA Case Control N=28	**Population**: SCI (n=20): Mean age=45.7±17.7yr; Gender: males=18, females=2; Level of injury: C=20; Time since injury=2hr-15d; The International Standard of Neurological Classification for SCI at discharge: A=5, B=2, C=3, D=6. Healthy Controls (n=8): Mean age=34.2±10.7yr; Gender: males=6, females=2. **Intervention:** All participants underwent Diffusion Tensor Imaging (DTI) with a 1.5T Avanto scanner with a 12-channel head and four-channel neck array using an echo-planar imaging (EPI) sequence at a repetition time/echo time (TR/TE) =8000/76ms and a resolution of 128X128 over a 20cm field of view (FOV). Images included sagittal T2 (TR/TE=4000/109ms), fluid-attenuated inversion recovery (TE/TR/echo train=8000/102ms/13), and axial T2 and T2* images. Regions of interest included upper (lower brainstem-lower C2), mid (upper C3-lower C5), and lower (upper C6-lower T1) regions. Medical records were reviewed to determine the extent of neurological deficit (e.g., quadriplegia,	1. ADC was significantly lower in the SCI group in the upper (p=0.013), mid (p<0.001), and lower (p<0.001) regions when compared to healthy controls. 2. There were no significant differences in FA when comparing SCI to healthy controls at all three regions (p>0.05). 3. SCI showed significantly lower RA in the mid region when compared to healthy controls (p=0.037). There was no significant difference in RA for the upper and lower regions (p>0.05). 4. There were no significant differences in VR when comparing SCI to healthy controls at all three regions (p>0.05). 5. Whole cord Diffusion Tenor Imaging parameters showed significantly lower ADC and RA in participants with SCI (p<0.001; p=0.022, respectively). 6. Whole cord ADC, FA, and RA were significantly lower in SCI with hemorrhage compared to controls (p<0.001; p=0.0037; p<0.001,

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	hemiplegia, radiculopathy, etc.). **Outcome Measures**: Apparent diffusion coefficient (ADC); fractional anisotropy (FA); relative anisotropy (RA); volume ratio (VR).	respectively). However, VR was significantly higher (p=0.008). 7. Only whole cord ADC and RA were significantly higher in quadriplegic SCI compared to healthy controls (p<0.001; p=0.023, respectively). 8. ADC, FA, and RA parameters at the injury site of all SCI were significantly lower compared to whole-cord healthy control Diffusion Tensor Imaging parameters (p=0.031; p<0.001; p<0.001, respectively). Whereas VR was significantly higher at the injury site (p<0.001).
Facon et al., (2005) France Case Control N=26	**Population:** *SCI group (n=15)*: Mean age: 53.9yr; Gender: males=10, females=5; Injury etiology: metastasis (n=4), degenerative (n=6), spondylodiscitis (n=5); Level of injury: C1-L1; Time since injury: >4yr. *Healthy Control (CG) group (n=11)*: Mean age: 36.7yr; Gender: males=8, females=3. **Intervention:** Researchers aimed to evaluate the diagnostic accuracy of diffusion tensor imaging (DTI) in individuals with SCI and healthy controls. Comparisons were also made against T2-weighted fast spin echo (FSE). **Outcome Measures:** Apparent Diffusion Coefficient (ADC), Fractional Anisotropy (FA).	1. For the healthy subjects, averaged ADC values ranged from 0.00096mm^2/s to 0.00105mm^2/s and averaged FA values ranged from 0.745 to 0.751. 2. Ten individuals had decreased FA (0.67), and one had increased FA values (0.831); only two individuals had increased ADC values (1.03). 3. There was a statistically significant difference in the FA values CG and SCI groups (p=0.012). 4. FA had a much higher sensitivity (SE=73.3%) and specificity (SP=100%) in spinal cord abnormalities detection compared with T2-weighted FSE imaging (SE=46.7%, SP=100%) and ADC (SE=13.4%, SP=80%).

Discussion

Studies have showed that the diagnostic value/psychometrics of different DTI measures such as apparent diffusion coefficient, fractional anisotropy, radial diffusivity, axial diffusivity, mean diffusivity, relative anisotropy, and volume ratio are highly statistically significant. In 2005, Facon et al., (2005) found that there was a statistically significant difference in the fractional anistrophy values between healthy controls and those with SCI groups. In particular, fractional anistrophy had a much higher sensitivity (SE=73.3%) and specificity (SP=100%) in spinal cord abnormalities detection compared with T2-weighted FSE imaging (SE=46.7%, SP=100%) and ADC (SE=13.4%, SP=80%). Koskinen et al., (2013) reveal that DTI revealed SCI pathology, which was undetectable using conventional MRI. Numerous studies including those by Choe et al., D'Souza et al., (2017), Shanmuganathan et al., (2008), Shanmuganathan et al., (2017), Kim et al., (2015), Koskinen et al., (2013) demonstrate a statistical difference in fractional anistrophy, axial diffusivity, radial diffusivity, apparent diffusion coefficient, relative anisotropy, and volume ratio values between healthy controls and those with SCI. Shanmuganathan et al., (2008) demonstrates that whole cord relative anisotropy, fractional anistrophy, and relative anisotropy were significantly lower in SCI with hemorrhage compared to controls, while volume ratio was significantly higher. Interestingly, they note that there was no significant differences in fractional

anistrophy when comparing SCI to healthy controls. Overall, DTI parameters show considerable diagnostic value, in particular, in its high sensitivity and specificity and in detecting pathology not seen on MRI.

The evidence behind using DTI as a prognostication tool is mixed. Various studies have examined different DTI measures such as apparent diffusion coefficient, fractional anisotropy, radial diffusivity, axial diffusivity, mean diffusivity and their relationships with a number of functional and injury classification scores including International Standards for Neurological Classification of SCI, Functional Independence Measure, Spinal cord independence measure III, Frankel grading system score, American Spinal Injury Association motor score, modified Barthel index score and Abbreviated Injury Scale. Fractional anistrophy has shown promise as a prognostication tool.

In a 2013 case control study by (Koskinen et al.) the fractional anistrophy values in the SCI group were positively correlated with the motor and sensory scores of The International Standard of Neurological Classification for SCI. Moreover, the fractional anistrophy values in the same group were positively correlated with the motor subscale of Functional Independence Measure.

In 2017, (D'Souza et al.) found that there was a statistically significant positive correlation between fractional anistrophy values at the level of injury and Frankel grading system score. In contrast, there was no significant correlation between mean diffusivity at the level of injury and Frankel grading system score.

Shanmuganathan et al., (2017) demonstrate that axial diffusivity was significantly correlated with presence of hemorrhagic contusion, The International Standard of Neurological Classification for SCI, and spinal cord independence measure III. Mean diffusivity, axial diffusivity, and radial diffusivity were significant predictors of The International Standard of Neurological Classification for SCI motor score at the 1-year follow-up for participants with or without hemorrhage spinal cord injury. However, fractional anisotropy was not a significant predictor in the model. Moreover, mean diffusivity, axial diffusivity, fractional anistrophy, and radial diffusivity were not significant predictors of spinal cord independence measure III at 1-year follow-up for both hemorrhagic and non-hemorrhagic spinal cord injury.

Meanwhile, Choe et al., found that there were no significant relationships between DTI indices and total International Standard of Neurological Classification for SCI scores from different spinal cord columns.

Conclusion

There is level 3 evidence (from one case control study; Choe et al., 2017) that there may be no significant relationship between DTI incidences and total International Standard of Neurological Classification for SCI scores either at baseline or follow-up in individuals with SCI.

There is level 3 evidence (from one case control study; (D'Souza et al., 2017) that there may be a significant positive relationship between fractional anisotropy and Frankel grading system scores, but no relationship between mean diffusivity and Frankel grading system scores.

There is level 3 evidence (from seven case control studies; Choe et al., 2017, (D'Souza et al., 2017, Ellingson et al., 2008a, Facon et al., 2005, Kim et al., 2015, Shanmuganathan et al., 2008, Shanmuganathan et al., 2017) that DTI may be an effective tool to measure microstructure abnormalities in individuals with an SCI compared to healthy controls.

There is level 3 evidence (from one case control study; (Shanmuganathan et al., 2017) that axial diffusivity may be positively correlated with the presence of hemorrhagic contusion, International Standard of Neurological Classification for SCI motor scores, and spinal cord independence measure III at both baseline and follow-up.

There is level 3 evidence (from one case control study; (Shanmuganathan et al., 2017) that axial diffusivity, radial diffusivity, and mean diffusivity may be a significant predictor of International Standard of Neurological Classification for SCI motor scores, but not spinal cord independence measure III scores, for both individuals with and without SCI.

There is conflicting level 3 evidence against (from one case control study; (Ellingson et al., 2008a), and one observational study; (Wang et al., 2016) and level 3 evidence for (from one case control study; (Koskinen et al., 2013) that DTI grading may have prognostic value in determining motor and sensory scores in individuals with SCI.

DTI has value as a diagnostic imaging tool to evaluate microstructural and spinal cord abnormalities in individuals with SCI.

There is conflicting evidence as to which observations from DTI can be used to predict current and future outcomes.

DTI may be effective for predicting relationships between different SCI abnormalities within individuals.

7.0 Summary

There is level 4 evidence (from one case series study; (Karpova et al., 2013), and two observational studies; (Ghasemi et al., 2015, Yasin et al., 2017) that MRI has strong inter-observer correlation, sensitivity, specificity, predictive value, and diagnostic accuracy in detecting and evaluating SCI in individuals.

There is level 5 evidence (from one case series study; (Schroeder et al., 2016) that the incidence of surgical treatment and spinal decompression is not significantly different between individuals based on the presence of signal intensity on an MRI.

There is conflicting level 3 evidence (from one cohort study; (Mabray et al., 2016), one case control study; (Seif et al., 2018), two case series; (Flanders et al., 1996), (Wilson et al., 2012), and six observational studies; (Aarabi et al., 2017, Schaefer et al., 1992, Selden et al., 1999, Song et al., 2016, Takahashi et al., 1993, Zohrabian et al., 2016) and level 5 evidence (from one observational study (Wang et al., 2016) that MRI is effective in determining microstructural measurements and can reliably predict AIS classification, motor score and status and progression of injury in individuals with SCI and controls.

There is level 5 evidence (from one cohort study; (Martinez-Perez et al., 2017) that early MRI has prognostic value in its ability to evaluate ligamentous injury and edema which are predictors of poor neurologic outcome.

There is level 5 evidence (from one observational study; (Miyanji et al., 2007) that MRI can be used to detect hemorrhage, edema, and cord swelling in individuals with SCI. A greater number of positive detections were significantly associated with increased SCI severity and American Spinal Injury Association classification.

There is level 5 evidence (from two observational studies; (Boldin et al., 2006; Shepard & Bracken 1999) that MRI may be used to predict complete SCI given the detection of hemorrhage and edema in individuals with SCI.

There is level 5 evidence (from one observational study; (Dalkilic et al., 2018) that MRI could be used to assess hematoma length and predict AIS classification at baseline.

There is level 5 evidence (from one observational study; (Matsushita et al., 2017) that MRI is effective in detecting spinal microstructures which can be used to effectively predict American Spinal Injury Association motor scores, and Frankel D scores in individuals with SCI.

There is level 5 evidence (Martinez-Perez et al., 2017) that an early MRI may have prognostic value in individuals with SCI without CT evidence of trauma.

There is level 5 evidence (from an observational study (Ouchida et al., 2016) that MRI may not be an effective diagnostic or prognostic indicator of injury in individuals diagnosed with SCI without radiographic abnormality.

There is level 3 evidence (from one case control study; Choe et al., 2017) that there may be no significant relationship between DTI incidences and total International Standard of Neurological Classification for SCI scores either at baseline or follow-up in individuals with SCI.

There is level 3 evidence (from one case control study; (D'Souza et al., 2017) that there may be a significant positive relationship between fractional anisotropy and Frankel grading system scores, but no relationship between mean diffusivity and Frankel grading system scores.

There is level 3 evidence (from seven case control studies; Choe et al., 2017, (D'Souza et al., 2017, Ellingson et al., 2008a, Facon et al., 2005, Kim et al., 2015, Shanmuganathan et al., 2008, Shanmuganathan et al., 2017) that DTI may be an effective tool to measure microstructure abnormalities in individuals with an SCI compared to healthy controls.

There is level 3 evidence (from one case control study; (Shanmuganathan et al., 2017) that axial diffusivity may be positively correlated with the presence of hemorrhagic contusion, International Standard of Neurological Classification for SCI motor scores, and spinal cord independence measure III at both baseline and follow-up.

There is level 3 evidence (from one case control study; (Shanmuganathan et al., 2017) that axial diffusivity, radial diffusivity, and mean diffusivity may be a significant predictor of International Standard of Neurological Classification for SCI motor scores, but not spinal cord independence measure III scores, for both individuals with and without SCI.

There is conflicting level 3 evidence against (from one case control study; (Ellingson et al., 2008a), and one observational study; (Wang et al., 2016) and level 3 evidence for (from one case control study; (Koskinen et al., 2013) that DTI grading may have prognostic value in determining motor and sensory scores in individuals with SCI.

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9.0 Abbreviations

ASIA	American Spinal Injury Association
CT	Computed Tomography
DTI	Diffusion Tensor Imaging
MRI	Magnetic Resonance Imaging
SCI	Spinal Cord Injury