Clinical Article

Winner of the Char Publications Registrars' Writing Competition 2010

Acute traumatic cervical spinal cord injuries: Correlating MRI findings with neurological outcome

M ter Haar, SM Naidoo, S Govender, P Parag and TM Esterhuizen

Abstract

Study design:

Retrospective, observational, cohort study.

Objectives:

To evaluate whether quantitative and qualitative magnetic resonance imaging (MRI) assessments after acute traumatic cervical spinal cord injuries (SCI) correlate with the patient's neurological status and if they are predictive of outcome at long-term follow-up.

Materials and methods:

Eighty-eight patients (77 male, 11 female) with traumatic cervical spinal cord injuries who were admitted to the spinal unit, were evaluated over a period of five years (Jan 2004–Dec 2008). Neurological impairment was classified using the Frankel classification both on admission and discharge. MR imaging was done on all patients using both T1- and T2-weighted sagittal scans, axial T2-weighted scans and axial gradient recalled echo imaging (for evaluation of haemorrhage). Three quantitative imaging parameters (maximum spinal cord compression [MSCC], maximum canal compromise [MCC], and length of lesion) as well as five qualitative parameters (intramedullary haemorrhage, cord oedema, cord swelling, disc herniation and soft tissue injury) were evaluated and correlated to the patients' neurological outcome.

Results:

Patients with a complete motor and sensory SCI (Frankel A) had higher frequencies of intramedullary haemorrhage ($p<0.001$), cord swelling ($p=0.002$) and cord oedema ($p<0.001$) compared to the incomplete SCI (Frankel grade B, C and D) and those without any neurology (Frankel grade E). Patients with complete SCI also had a more substantial MSCC ($p=0.008$), MCC ($p=0.009$) and lesion length ($p=0.001$) compared to the other two groups. The length of lesion ($p=0.019$) and intramedullary haemorrhage ($p=0.001$) correlate with baseline neurology. MSCC ($p=0.063$), length of lesion ($p=0.011$) and intramedullary haemorrhage ($p=0.036$) were predictive of a poor neurological outcome.

Conclusion:

The study demonstrated MR imaging to be a useful tool in prognosticating a patient's potential for neurological recovery. It indicated that MSCC, length of lesion and intramedullary haemorrhage are associated with a poor prognosis for neurological recovery.

Introduction

Injuries of the cervical spine are commonly associated with devastating trauma to the spinal cord with consequential neurological impairment. Prior to the use of magnetic resonance imaging (MRI) as a diagnostic and prognostic modality, neurological recovery according to the Frankel classification[9] has been the only predictive value in SCI.[15] Currently MRI is the radiological modality of choice in spinal cord injuries (SCI) to assess the degree of spinal cord damage and possible neurological recovery.

Several studies have been done on qualitative findings such as cord haemorrhage, cord oedema, cord contusion, soft tissue injuries and herniated disc, correlating them with the degree of neurology deficit and neurological recovery in cervical SCI.[2-8,10,15,16,19] A few studies have focused on quantitative MRI values in patients with acute cervical SCI.[8,20] Fehlings *et al*[21] developed a reliable quantitative radiological method for assessing spinal cord compression and spinal canal compromise. In a study by Miyanji *et al*[8] both quantitative and qualitative MRI parameters were combined for the prediction of the patient's neurological recovery.

The purpose of our study was to correlate both quantitative and qualitative MRI parameters to the patients' neurological status and assess them as possible predictors of long-term neurological outcome.

Materials and methods

Population group

A retrospective cohort analysis was performed on 88 consecutive patients with acute cervical SCI due to trauma in the KwaZulu-Natal province, South Africa. All the patients were initially treated and stabilised in the referral hospitals and then referred to the spinal unit at King George V hospital in Durban for assessment and definitive treatment. None of the patients in the study received any methylprednisolone as part of the initial and subsequent management. The study was over a five-year period extending from January 2004 to December 2008. Our patient selection criteria were as follows: **Inclusion criteria** – 1) All adult patients who had acute cervical spinal cord injuries between 1 January 2004 and 31 December 2008 who had an MRI done of their cervical spine. 2) Only patients who had been treated in the spinal unit. **Exclusion criterion** – 1) Patients who had acute cervical spinal cord injuries during this period but who did not have an MRI done.

Neurological assessment

A total of 88 patients, (77 male, 11 female) were examined and recorded. The Frankel classification system[9] for motor and sensory score was used as the neurological assessment on admission and on last visit. The patients were then divided into three groups according to the severity of their SCI: Group A were complete spinal cord injuries (Frankel grade A); Group B were incomplete spinal cord injuries (Frankel grade B, C or D); and Group C were those with no neurology (Frankel grade E). The initial Frankel grading on admission was compared to the Frankel grading on discharge from the hospital as well as the Frankel grading on the last follow-up visit to determine any neurological improvement or deterioration.

MR imaging

An MRI scan of the C-spine was done on all the hospital patients. The average time to scan was eight days.

MRI was obtained using a 1.5 Tesla superconducting MR scanner (Siemens Symphony 1.5T) with a surface coil. T1-weighted images were obtained with an echo time of 14 milliseconds and a pulse repetition time of 525 milliseconds, while T2-weighted images were obtained with an echo time of 110 milliseconds and a repetition time of 3 400 milliseconds. The slice thickness was 3 mm for T1-weighted sequences and 2 mm for the T2-weighted sequences.

Both a T1- and T2-weighted sagittal and T2-weighted axial imaging were done on all the patients. Gradient recalled echo sequence to determine the presence of cord haemorrhage was also performed. These images were then examined by a radiologist. The radiologist was blinded to the patients' clinical and neurological data. The assessment and interpretation of the MRI images were divided into quantitative and qualitative measures.

Three quantitative measures were used: maximum canal compromise (MCC), maximum spinal cord compression (MSCC) and length of lesion. Mid-sagittal T1- and T2-weighted imaging were used to determine the MCC and MSCC respectively as described by Fehlings *et al*.[21] This value was determined by measuring the distance of the canal or spinal cord one segment above and below the lesion respectively to calculate the average distance. The distance was then measured at the site of the lesion and expressed as a percentage of the average (see *Figure 1*).

The length of the lesion was determined on T2-weighted images. This length was determined as the distance between the most cephalic and most caudal extent of the cord signal (*Figure 1*).

The qualitative MRI findings that were used in addition to the quantitative variables, as determined by T2-weighted imaging, included cord haemorrhage, cord oedema, cord swelling, disc herniation and soft tissue injury (STI).

The level of the SCI was determined by the radiological assessment of the osseous injury on a lateral C-spine X-rays as well as the level of maximum cord compression as seen on MRI.

Statistical analysis

Univariate and multivariable analysis was used to assess quantitative and qualitative factors associated with neurological outcome. Quantitative MRI findings were non-normally distributed, thus non-parametric Kruskal-Wallis tests were used to compare their distributions between the three neurological groups. Pearson's Chi-square tests were used to compare the proportions of the qualitative variables between the three groups. Two multivariable linear regression models were created to assess the independent roles of the various factors in predicting neurological status at admission and discharge. The dependent variables were scored between 1 and 3, with 1 being Group A and 3 being Group C. A backwards modelling approach was used, with probability of removal set at p≥0.10. Step one included all variables which were found to be significantly associated with the dependent variables on univariate analysis. The model to predict follow-up Frankel score was not adjusted for baseline Frankel score due to extensive co-linearity between the baseline Frankel score and some of the predictors. SPSS version 15.0 (SPSS Inc., Chicago, Illinois) was used to analyse the data. A p-value <0.05 was considered as statistically significant.

Results

From the total of 88 patients that had SCI, 77 (87%) were male and 11 (13%) were female (see *Table I*). The average age was 37 years (range 18–87). The most common mechanism of injury was motor vehicle accidents (MVA) (65%), and the most frequently involved level was C5 through C6 (33%).

On discharge from the hospital 42 (48%) patients had no neurology

Most of the patients had an incomplete lesion on admission - 39 (44%). The mean follow-up of the patients was 12.4 months. Of the total of 88 patients, four were lost to follow-up. On discharge from the hospital 42 (48%) patients had no neurology.

The most common type of surgery performed on the patients was anterior spinal fusion (ASF). Median time to surgery was 32 days. The reason for the delay in surgical treatment was mainly due to the time lost during the referral from other hospitals as well as the difficulty in obtaining an MRI scan.

Analysis of quantitative MRI variables *(see Figure 2)*

The mean extent of MCC was significantly different between the patients with complete SCI and incomplete SCI (p=0.009). A more substantial degree of MCC was seen in the complete group. There was very little difference in the MCC between the incomplete group and those without neurology.

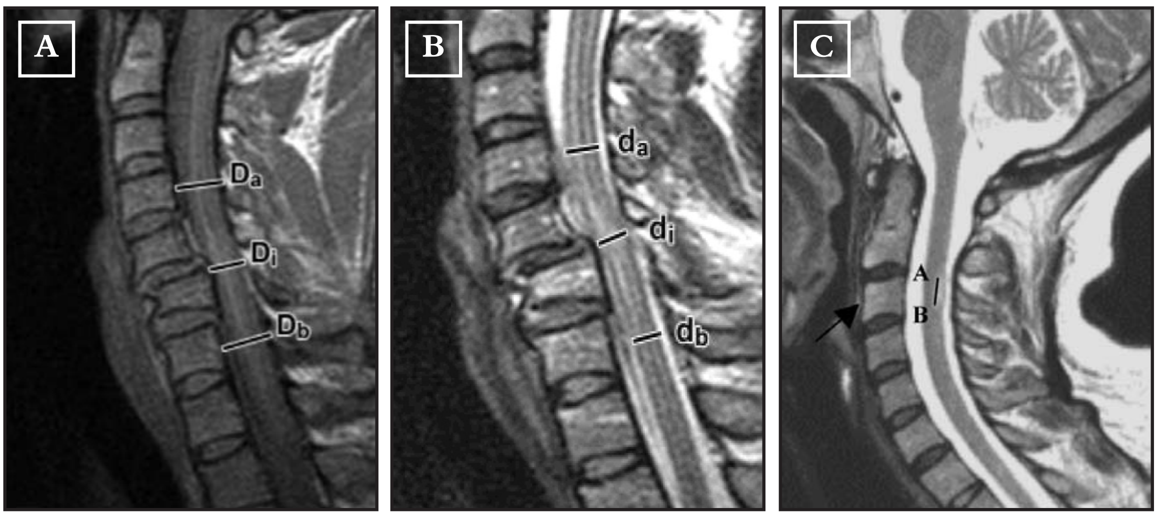

Figure 1 Calculation of MRI values

A: Mid-sagittal T1-weighted MR image shows the distances of the spinal cord at the injury site (Di), one segment below the injury site (Db), and one segment above the injury site (Da). **This is used to estimate MCC.**

B: Mid-sagittal T2-weighted MR image show the distance of the spinal canal at the injury site (di), one segment below above the injury site (da). **This is used to estimate MSCC.**

C: Mid-sagittal T2-weighted image shows the distance from the most cephalic extent (A) to the most caudal extent (B) of the injury. **The length of the lesion is the distance between A and B.**

The mean extent of the MSCC was also significantly different between the groups (p=0.008). A more substantial MSCC was found in the patients with a complete lesion compared to the other two groups. Similar to the findings with MCC there was little difference in the MSCC between the incomplete group and those without neurology.

There was a significant difference in the length of the lesion among the three groups (p=0.001). The complete SCI had a median length of 47.8 mm, followed by the incomplete SCI with a median length of 22.6 mm and the SCI without neurology with a median length of 8.2 mm.

Analysis of qualitative MRI variables *(see Figure 3)*

The frequencies of intramedullary haemorrhage (p<0.001), cord oedema (p<0.001) and cord swelling (p=0.002) differed significantly among the three neurological groups. These variables were directly associated with the severity of the injury. There was, however, no significant difference in the frequencies between the three groups for STI (p=0.54) and disc herniation (p=0.87). The complete SCI had the highest frequencies in all five variables, followed by the incomplete SCI and the SCI without any neurology. The SCI without any neurology did not show any haemorrhage on MRI.

Table I: Summary of patients

Characteristics	No of patients (n=88)
Mean age	37 (18-87)
Male	77 (87%)
Female	11 (13%)
Severity of SCI:	
Complete (Frankel grade A)	18
Incomplete (Frankel grade B,C & D)	39
No injury (Frankel grade E)	31
Level of SCI:	
C1	1
C1/C2	1
C2	10
C2/C3	2
C3/C4	9
C4/C5	14
C5	6
C5/C6	29
C6	1
C6/C6	11
C7	2
C7/T1	2
Mode of injury:	
MVA	57
Fall	21
Assault	6
Diving	3
Gunshot	1

The total number of patients with spinal cord lesions (quantitative or qualitative variables) on MRI differed among the three groups. All (100%) with complete SCI had MRI lesions, while only 82% of the incomplete SCI had MRI lesions compared to only 35% of SCI without neurology that had MRI lesions.

Analysis of possible predictors of outcome *(see Table II)*

Multivariable linear regression was used to assess both the qualitative and quantitative variables as potential predictors of Frankel grading on admission and discharge.

The best predictors of baseline Frankel grading were the length of lesion (p=0.019) and presence of intramedullary haemorrhage (p=0.001). Both were negatively associated with the Frankel grading score, thus they were associated with poorer Frankel grading scores.

The best model for predicting Frankel grading at follow-up was MSCC (p=0.063), length of lesion (p=0.011) and intramedullary haemorrhage (p=0.036). These variables also predicted poorer Frankel scores at discharge as they were negatively associated with the outcome.

The diagnosis of the initial injury is critical in order to predict an accurate functional prognosis

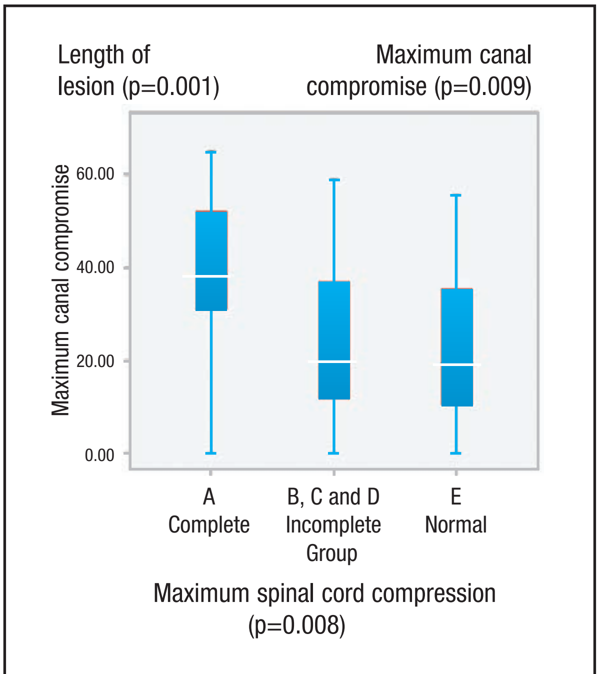

Figure 2. Analysis of quantitative MRI variables

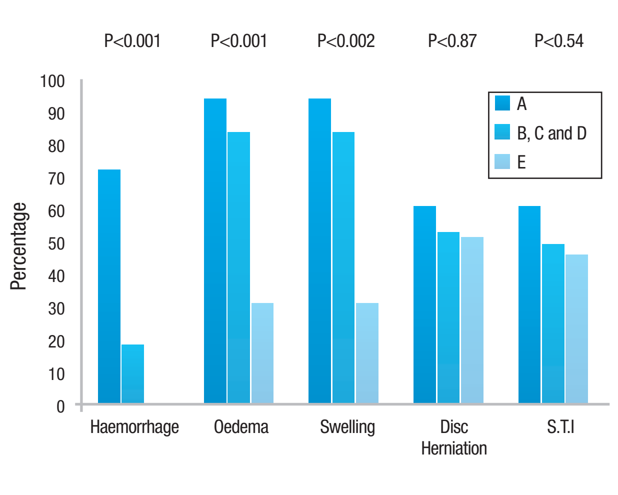

Figure 3. Analysis of qualitative MRI variables

Discussion

Previously the Frankel classification has been the only method to determine the neurological status and possible recovery of patients after SCI. The use of MRI is now well established as the method of choice in examining patients with SCI, and correlating it with their neurological status and using it as a possible predictor of neurological recovery.[2-8,10,11,13,19] Although CT scan is superior in detecting precise bony injuries MRI is the most sensitive modality for detecting spinal cord damage, disc protrusions and paraspinal soft tissue injuries.[1,2,10,11,14,17] The diagnosis of the initial injury is critical in order to predict an accurate functional prognosis. The best time for prognostic imaging appears to be within the first 24-72 h of the injury and 2-3 weeks later.[3,4,11,12,17] In our study the mean time to MRI scanning was eight days. This delay was due to the difficulty in obtaining an MRI scan at the Radiology department within such a short period of time.

The results of our study show that after using multivariable regression analysis, intra-medullary haemorrhage and length of lesion correlated significantly with baseline neurological status. Only intramedullary haemorrhage, MSCC and length of lesion were key predictors of neurological recovery after an SCI.

The fact that cord oedema and cord swelling was not statistically significant in correlating with baseline neurology, or as a predictor of outcome, was most probably due to the confounding effect of cord haemorrhage. Patients with a more substantial MSCC, length of lesion, cord haemorrhage, cord oedema and cord swelling, had lower Frankel gradings. The patients with complete SCI had a more substantial MCC, MSCC and length of lesion as well as a higher frequency of intramedullary haemorrhage, cord oedema, cord swelling, disc herniation and soft tissue injury compared to the incomplete injuries and neurologically healthy patients. The results of our study were very similar to those of Miyanji *et al*,[8] but we did not analyse for pre-injury stenosis in our qualitative variables. In addition they differed from our study in that they found a lower frequency of disc herniations in the complete SCI compared to the other two groups. Their study was a prospective, multicentre study while ours was a retrospective study done at one centre.

Quantitative MRI variables

Miyanji *et al*[8] and Rao and Fehlings,[20] noted that in most studies to date the qualitative parameters have been used to examine the association between imaging parameters and neurological outcome in SCI, but that there was a lack of studies in which the quantitative parameters (degree of spinal canal compromise, cord compression and length of lesion), are quantified. Kang *et al*[23] however attempted to quantify canal compromise by using lateral cervical radiographs. Hayashi *et al*[18] quantified cord compression at the level of maximum compression by using MR imaging and dividing it into mild (cord diameter of more than two-thirds) and severe cord compression (cord diameter of less than two-thirds). We used an objective method, which has previously been approved to be reliable, standardised and objective, to quantify MR images obtained from patients with SCI.[20,21]

In our study there was a significant difference in all three parameters assessed among patients with a complete SCI, those with incomplete SCI and neurologically healthy patients. In particular, it was much greater in the complete injuries for MSCC, MCC and length of lesion compared to the other two groups.

Table II: Results of multivariable linear regression analysis of predictors for baseline and follow-up Frankel grading

Model no	R2 value	Dependent variable	Independent variables	Coefficient	T-value	p-value
1	0.358	Baseline Frankel grading	Length of lesion	-0.006	-2.417	0.019
			Haemorrhage	-0.612	-3.477	0.001
			constant	2.295	21.756	<0.001
2	0.334	Follow-up Frankel grading	MSCC	-0.011	-1.893	0.063
			Length of lesion	00.008	-2.637	0.011
			Haemorrhage	-0.409	-2.149	0.036
			Constant	2.607	20.900	<0.001

The relation between bone and soft tissue injury and underlying cord damage has not yet been fully clarified. Although Miyanji *et al*[8] in their study found that there was a correlation between old age and more substantial cord compression most probably due to underlying pre-existing degenerative changes, Flanders *et al*[1] found that pre-existing cervical spondylosis did not directly relate to the degree of injury.

In theory, patients with pre-existing spinal stenosis and degenerative spondylosis should be predisposed to a more severe spinal cord injury during hyperflexion and hyperextension of the cervical spine. Their explanation for this is the possibility that spinal cord injuries in elderly people, who usually have underlying cervical spondylosis, are less likely to be caused by sport-related activities or high speed motor vehicle accidents as in the younger population.

Their study also supports the perception that the degree of bone and soft tissue injury does not predict the resultant spinal cord injury.

Qualitative MRI variables

Although the cord is subjected to secondary insults following the initial trauma, it is generally accepted that the extent of cord damage is mainly caused by the amount of force at the initial impact.[24,25] Although the cord is fairly resistant to direct physical (structural) disruption, a very minor injury can cause significant cord malfunction. Several authors have described the most common MRI patterns of the cord following SCI, haemorrhage (Type I pattern), cord oedema (Type II pattern) and cord contusion (Type III pattern).[2,7,11,17] The presence of spinal cord haemorrhage on MRI represents the most severe form of spinal cord damage and is associated with very poor neurological function. These patients are more likely to have complete neurology.[2,6,7,10,11,15,16,19] Several authors[2,10,11] showed that cord haemorrhage was associated with a complete neurology which was irreversible with no chance of any neurological recovery. Other authors differ in this regard and showed that although the presence of cord haemorrhage was associated with a high degree of complete neurology and a poor prognosis in terms of neurological recovery, the presence of haemorrhage does not always imply complete neurology without the possibility of any recovery.[7,15,16,19] These authors agree that the size of the haemorrhage influences the severity of neurology. The presence of a small area of haemorrhage is often associated with incomplete neurology.

In a study by Boldin *et al*[7] the presence of haemorrhage of less than 4 mm was not associated with a complete SCI and showed a good prognosis compared to the patients with complete SCI who had a median haematoma length of 10.5 mm. Flanders *et al*[16] showed that patients with cord haemorrhage had better motor recovery of the upper extremities with very little improvement of the lower extremities. All authors agree that the absence of cord haemorrhage after SCI is associated with less neurological impairment and has a much better prognosis for neurological recovery.

The presence of cord oedema represents a less severe form of cord damage and is often associated with incomplete injuries and a favourable prognosis.[2,6,8,10,11,15,16]

Evidence of extensive cord oedema was associated with complete injuries[1,15,19] and a poor outcome. This has been confirmed in a study by Boldin *et al*,[7] who found that patients with complete injuries had significantly longer oedema (40-150 mm) and a worse outcome than patients with incomplete injuries (0-54 mm). According to Shepard and Bracken,[19] MRI evidence of cord oedema was the strongest predictor of reduced improvement in motor function. Patients with minimal or no cord changes on MRI are often associated with minimal neurological deficit and have the best prognosis, followed by those with cord oedema.[2,6,7,10,11]

Our study found similar results in our qualitative assessment to that of the literature. Cord haemorrhage, cord oedema and cord swelling were significantly more frequently associated with complete injuries. Although cord haemorrhage had a high association with complete neurology and is a predictor of poor neurological recovery, the possibility of neurological recovery was not excluded. Cord oedema and cord swelling had a high association with incomplete neurology but multivariable regression analysis showed it is not a predictor of neurological recovery.

Further studies, however, are needed, looking more specifically at the length of lesions for both cord haemorrhage and cord oedema in order to find a more precise correlation between MRI findings and neurological outcome.

As mentioned in the literature, it is very difficult to make an exact correlation between the static findings on MRI, which is an underestimation of the dynamic events of the spinal cord at the time of injury, and the severity of neurology. One can however correlate these quantitative and qualitative variables to the neurological status of the patient and, more importantly, it can be used in prognosticating a patient's potential for neurological recovery.

The study has shown that patients with complete injuries have a small chance of neurological recovery compared to those with incomplete neurology who have a much more optimistic prognosis. One should always remember that some patients recover far beyond the anticipated prediction and, conversely, others have minimal improvement from what initially appeared to be a minor injury.

In our study there was a significant difference in all three parameters assessed among patients with a complete SCI, those with incomplete SCI and neurologically healthy patients

Conclusion

In our study we found MRI to be a very useful tool in evaluating the patient with an SCI and that MRI findings can be correlated to the neurological status of the patient. It can also be used as a prognosticator for possible neurological recovery. We demonstrated that the presence of a more substantial MSCC, length of lesion and intramedullary haemorrhage are associated with a poor prognosis for neurological recovery.

First published in *The Specialist Forum,* September 2010 - another Char Publications journal.

References

1. Flanders AE, Schaefer DM, Doan HT, Gonzalez FC, Northrup BE. Acute cervical spine trauma: Correlation of MR Imaging findings with degree of neurological deficit. *Radiology* 1990;**177**(1):25-33.
2. Ramon S, Dominquez R, Ramirez L, *et al*. Clinical and magnetic resonance imaging correlation in acute spinal cord injury. *Spinal Cord* 1997;**35**:664-73.
3. Shimada K, Tokioka T. Sequential MR studies of cervical cord injury: correlation with neurological damage and clinical outcome. *Spinal Cord* 1999;**37**:410-5.
4. Takahashi M, Harada Y, Inoue H, Shimada K. Traumatic cervical cord injury at C3-4 without radiographic abnormalities: correlation of magnetic resonance findings with clinical features and outcome. *J. Orthopaedic Surgery* 2002;**10**(2):129-35.
5. Ishida Y, Tominaga T. Predictors of neurological recovery in acute central cervical cord injury with only upper extremity impairment. *Spine* 2002;**27**:1652-8.
6. Tewari MK, Gifti DS, Singh P, *et al*. Diagnosis and prognostication of adult spinal cord injury without radiographic abnormality using magnetic resonance imaging: analysis of 40 patients. *Surgical Neurology* 2005;**63**:204-9.
7. Boldin C, Raith J, Frankhauser F, *et al*. Predicting neurological recovery in cervical spinal cord injury with postoperative MR imaging. *Spine* 2006;**31**(5):554-9.
8. Miyanji F, Furlan JC, Aarabi B, *et al*. Acute cervical traumatic spinal cord injury: MR imaging findings correlated with neurological outcome. *Radiology* 2007;**24**(3):820-9.
9. Frankel HL, Hancock DO, Hyslop G, *et al*. The value of postural reduction in the initial management of closed injuries of the spine with paraplegia and tetraplegia. Part 1. *Paraplegia* 1969;**7**:179-92.
10. Schaefer DM, Flanders A, Northrup BE, *et al*. Magnetic resonance imaging of acute cervical spine trauma. Correlation with severity of neurological injury. *Spine* 1989;**14**(10):1090-5.
11. Bondurant FJ, Cotler HB, Kulkarni MV, *et al*. Acute spinal cord injury: a study using physical examination and magnetic resonance imaging. *Spine* 1990;**15**(3):161-8.
12. Weirich SD, Cotler HB, Narayana PA, *et al*; Histopathological correlation of magnetic resonance imaging signal patterns in a spinal cord injury model. *Spine* 1990;**15**:630-8.
13. Folman Y, El Masri W, *et al*; Spinal cord injury: prognostic indicators. *Injury* 1989;**20**(2):92-3.
14. Kalfas I, Wilberger J, Goldberg A, *et al*; Magnetic resonance imaging in acute spinal cord trauma. *Neurosurgery* 1988;**25**:295-9.
15. Schaefer DM, Flanders AE, Osterholm NL, *et al*. Prognostic significance of magnetic resonance imaging in the acute phase of cervical injury. *J Neurosurgery* 1992;**76**:218-23.
16. Flanders AE, Spettell CM, Tartaglino LM, *et al*. Forecasting motor recovery after cervical spinal cord injury: value of MR imaging. *Radiology* 1996;**210**;649-55.
17. Flanders AE, Croul SE. *Magnetic resonance imaging of the brain and spine*. Third edition 2002. Chapter 30;1769-806.
18. Hayashi K, Yone K, Ito H, *et al*. MRI findings in patients with cervical spinal cord injury who do not show radiological evidence of a fracture or dislocation. *Paraplegia* 1995;**33**(4):212-5.
19. Shepherd MJ, Bracken MB. Magnetic resonance imaging and neurological recovery in acute spinal cord injury: observations from the National Acute Spinal Cord Injury Study 3. *Spinal Cord* 1999;**37**:833-7.
20. Rao SC, Fehlings MG. The optimal radiological method for assessing spinal canal compromise and cord compression in patients with cervical spinal cord injury. 1. An evidence based analysis of the published literature. *Spine* 1999;**24**(6):598-604.
21. Fehlings MG, Rao SC, Tator CH, *et al*. The optimal radiological method for assessing spinal canal compromise and cord compression in patients with cervical spinal cord injury. Results of a multicenter study. *Spine* 1999;**24**(6):605-13.
22. Fehlings MG, Furban JC, Massicote EM, *et al*. Interobserver and intraobserver reliability of maximum canal compression and spinal cord compression for evaluation of acute traumatic cervical spinal cord injury. *Spine* 2006;**31**(15):1719-25.
23. Kang JD, Figgie MP, Boldmann HH. Sagittal measurements of the cervical spine in subaxial fractures and dislocations: an analysis of two hundred and eighty-eight patients with and without neurological deficits. *J. Bone Joint Surg Am* 1994;**76**(11):1617-18.
24. Ikata T, Iwasa K, Morimoto K, Tonai T, Taoka Y. Clinical considerations and biochemical basis of prognosis of cervical spinal cord injury. *Spine* 1989;**14**(10):1096-101.
25. Walker MD. Acute spinal cord injury. *N Engl J Med* 1991;**324**(26):1885-7.