Correlation of Quantitative MRI Parameters with Neurological Outcome in Acute Cervical Spinal Cord Injury

Abstract

Background: The unbearable morbidity and significant mortality associated with traumatic cervical spine injuries (T-CSIs) have been complicated by difficulties in outcome prediction. **Objectives:** This study aims to determine the correlation between quantitative magnetic resonance imaging (MRI) parameters and neurological outcome among patients with acute T-CSI. **Materials and Methods:** This is a prospective study in which patients with T-CSI were recruited over a 12-month period. ASIA Impairment Scale (AIS) at admission, 6 weeks, and 3 months was assessed. Mean spinal cord compression (MSCC), mean canal compromise (MCC), and length of lesion (LOL) were calculated from MRI at admission, and correlation with neurological severity and outcome was determined. The data were analysed using SPSS version 21. A P-value of less than 0.05 was considered significant for associations. **Results:** Sixty-nine patients were enrolled comprising 55 males and 14 females giving a male-female ratio of 4.9:1. Their ages ranged from 18 to 74 years with a mean age of 40.2 ± 15.1 years. Injuries were ASIA A in 55.1% and ASIA E in 7.2% on admission. The mean MSCC, MCC, and LOL were higher for ASIA A and B and lowest in ASIA E injuries. Patients with good AIS (D and E) had significantly lower MSCC on admission ($P = 0.032$) and at 6 weeks ($P = 0.000$), and the LOL was also lower on admission ($P = 0.000$), at 6 weeks ($P = 0.006$), and at 3 months ($P = 0.007$). None of MRI parameters predicted outcome. **Conclusion:** The MSCC, MCC, and LOL correlate with T-CSI severity but were not sufficient to predict outcome.

Keywords: *Cervical injury, MRI, neurology, outcome, quantitative parameters*

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Introduction

Spinal cord injury (SCI) occurs in all countries of the world with an annual incidence varying from 1.5 to 40 cases per million.[1] The situation in the developing world is compounded by a high incidence of spinal cord injuries and poor financial resources.[2] The severity of these injuries increases with ascending level making cervical injuries lethal. Unfortunately, cervical injuries are the most common sites of acute SCI (ASCI) worldwide and in most parts of Nigeria.[3-5]

Complete cervical SCI is a life-time disaster not only for its victims, but also the relatives who might have to accept the sudden change in the lifestyle of their loved ones if they eventually survive. Despite the significant milestones achieved in the management of traumatic spinal cord injuries, outcome of management of cervical cord injuries has remained guarded particularly in a developing country such as Nigeria.[3,6]

Management requires a life-time dedication of a multi-disciplinary team and full involvement of the patient's relations. Consequently, there has been a continuous evolution of parameters that could assess severity of injury and predict outcome. Beyond the clinical parameters, the search for objective and reproducible means of assessment of SCI has led to the study of some qualitative and quantitative magnetic resonance imaging (MRI) features. Most extensive studies have been on qualitative parameters and have elucidated the predictive significance of cord haemorrhage and cord oedema. However, there seem to be a paradigm shift towards evaluation of quantitative MRI parameters with promising outcomes. The knowledge and application of clinical and MRI-based outcome parameters will guide attending surgeons in not only planning treatment, but also answering the anxious queries of patients and relations based on objective parameters.

This study hopes to determine the relationship between MRI quantitative findings and early neurological outcome. The key assumption of the study is that the use of quantitative MRI parameters in ASCI will allow for a more detailed and reproducible statistical analysis.

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Materials and Methods

The study was a prospective hospital-based cohort study that was conducted among patients with acute traumatic cervical spine injury who presented to the Neurosurgical unit between January 2018 and January 2019.

Ethical approval for the study was obtained from the Health Research Ethics Committee (HREC) with registration number NHREC/05/01/2008B-FWA00002458-1RB00002323. Informed consent from patients/guardians who satisfy the inclusion criteria was obtained. Voluntary participation was emphasized to the participants, and other principles of the Helsinki Declaration for medical research on human subjects were also adhered to.[7]

Inclusion criteria

1. Patients with clinically diagnosed traumatic cervical spine injury aged 18–65 years;
2. Patients who presented and had MRI within 14 days of trauma;
3. Non-operatively managed patients.

Exclusion criteria

Moderate and severely head injured in whom proper neurological assessment was limited.

Data collection

All patients who met the inclusion criteria were consecutively recruited over the study period and had their neurological severity of injury assessed using the AIS form on admission, at 6 weeks post trauma or discharge or whichever comes first, and at 3 months post trauma. Based on the AIS, patients were categorized into three groups:

Group I: Complete injury (AIS A);
Group II: Incomplete injury (AIS B–D);
Group III: Neurologically normal (AIS E).

For the purpose of this research, neurological outcome (AIS A–E or death) was defined by the state of the patient at discharge, at 6 weeks, and 3 months post injury (if patient is still on admission). AIS A, B, and C were considered as poor neurological outcome, whereas ASI D and E were considered as good outcome. The acute phase of SCI

has been described as the first 2 weeks post injury.[8] Therefore, all patients had MRI done within 14 days of injury for this study. MRI of patients was studied by an independent radiologist who measured the respective diameters for calculation of the MCC and MSCC, LOL, and radiologic level of injury. Based on measurements by the radiologist, the MSCC, MCC, and the LOL were calculated using the equation as described by Fehlings *et al.*[9]

MSCC and LOL were measured on a T2-weighted image [Figure 1a and b], whereas the MCC was measured on a T1-weighted image [Figure 1c]. Mean values for each of the neurological subgroups were then calculated. The level of injury was defined as the site of most severe involvement on MRI.

Mean spinal cord compression (MSCC)

$$\left\{ 1 - \frac{D_i}{\frac{1}{2}(D_a + D_b)} \right\} \times 100,$$

where D_i is the mid-sagittal diameter of the cord at the injury site;

D_a is the mid-sagittal diameter of the cord at one segment above injury;

D_b is the mid-sagittal diameter of the cord at one segment below injury.

Length of lesion (LOL)

The LOL was measured on T2WI as the total length of abnormal appearing cord segment congruent with and above and below the primary site of injury [Figure 1c].

Mean canal compromise (MCC)

$$\left\{ 1 - \frac{d_i}{\frac{1}{2}(d_a + d_b)} \right\} \times 100,$$

d_i is the spinal canal diameter at the level of injury;

d_a is the first unaffected level above the injury;

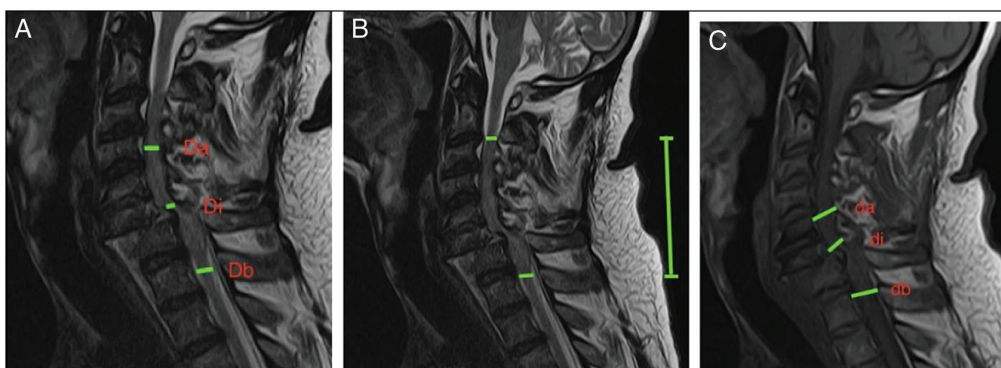d_b is the first unaffected level below the injury.

Figure 1: (a) T2-weighted image for MSCC. (b) Mid-sagittal T2WI for LOL. (c) T1-weighted image for MCC
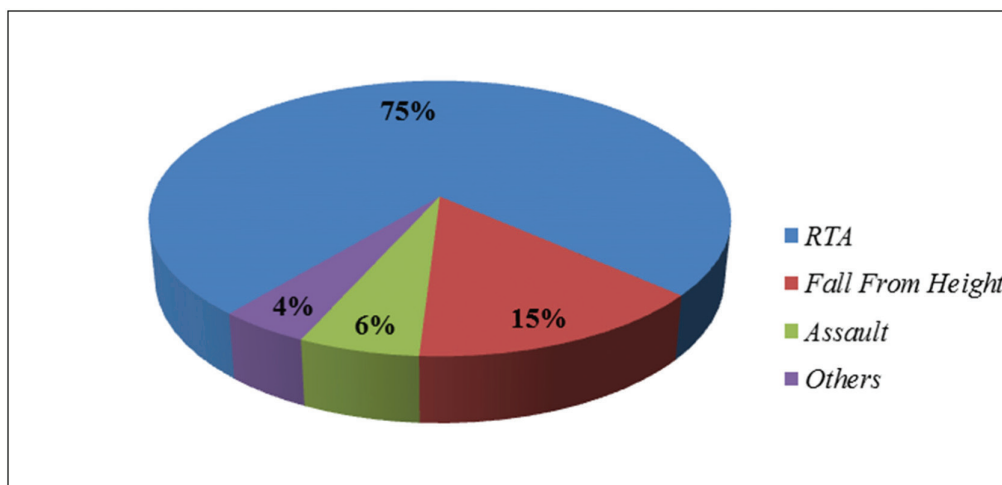
Figure 2: Causes of cervical spinal cord injuries

All patients were resuscitated based on the advanced trauma life support (ATLS) protocol. Non-operative management which encompassed cervical protection, deep venous thrombosis (DVT) prophylaxis, analgesics, and prevention of pressure ulcers, early physiotherapy, and prevention/treatment of complications was instituted.

Cervical spine protection was achieved using appropriate-sized Philadelphia cervical collar.

All patients at risk were placed on DVT prophylaxis which included thrombo-embolus deterrent stockings and oral Dabigatran. Patients at high risk of developing pressure ulcers were nursed on water mattress in addition to regular turning.

Early physiotherapy was commenced in all patients as appropriate, and ambulation commenced after dynamic lateral cervical spine X-ray after 6 weeks of cervical immobilization when indicated.

All data obtained from the study subjects were subjected to statistical analysis using the Statistical Package for Social Sciences (SPSS) Version 21 Statistical Software. Normality of data was determined using the Shapiro–Wilk test. Associations between quantitative MRI parameters and AIS on admission, discharge/6 weeks, and at 3 months post injury were statistically determined. Continuous variables were analysed using Student's *t*-test and Wilcoxon-signed ranked test if the normality test failed. The correlative studies were assessed statistically by applying Pearson's χ^2 test for qualitative parameters and analysis of variance (ANOVA) for quantitative parameters or Kruskal–Wallis test if the normality test failed. Binary logistic regression model was used to analyse for predictors of outcome. The statistical significance level accepted was $P < 0.05$.

Results

Sociodemographic characteristics

On admission, data from 69 patients were collated and analysed comprising of 55 males (79.7%) and 14 females (20.3%) giving a male–female ratio of 4.9:1. Their ages ranged from 18 to 74 years with a mean age of 40.2 ± 15.1.

Patients in their third and fourth decades were the most affected. This age group (21–40 years) accounted for 52.1% of all patients [Table 1]. Mean age for males was 40.07 ± 15.07, whereas that of females was 40.6 ± 15.7. No difference in mean age between sex was found (*t*-test, $P = 0.901$).

Aetiology of cervical spine injury

The most common cause (75.4%) of cervical spine injury was road traffic accidents [Figure 2]. Of these, motor vehicular accidents (49.3%) were the most frequent. Motorcycle crash (24.6%) and fall from Palm trees (13.0%) were also important causes of injury.

Quantitative MRI parameters

The quantitative MRI parameters passed the normality test. The MSCC ranged between −1.50% and 74.20% and has a mean of 30.1 ± 20.7. The MCC also ranged from −108.7% to 57.5% with a mean of 14.0 ± 27.6. The values for LOL ranged from 0.0 to 113.7 mm with a mean of 34.9 ± 30.8.

Pattern of quantitative MRI parameters and variations with severity of clinical injury

Patients with ASIA E had the lowest mean for each of the MSCC, MCC, and LOL. There was no significant difference in mean MSCC, MCC, and LOL between various neurological status on admission as determined by one-way ANOVA [Table 2]. None of the patients had ASIA D on admission.

Multivariate analysis of the MRI parameters among the three neurological groups (I, II, and III) showed the LOL to be statistically significant between the groups at 6 weeks ($P = 0.031$) and at 3 months ($P = 0.027$) but not on admission ($P = 0.266$). The changes with MSCC and MCC were not significant [Table 3].

When patients were re-grouped into good AIS (ASIA D and E) and poor AIS (ASIA A–C) groups, patients with good AIS at admission, 6 weeks, and at 3 months were found to have significantly lower initial mean MSCC and LOL when compared with those with poor AIS [Table 4].

Do quantitative MRI parameters predict neurological outcome?

The outcome model showed good fit for the data by the Omnibus test of coefficients and Hosmer–Lemeshow test. On bivariate logistic regression analysis of possible predictors of outcome, none of MSCC, MCC, or LOL was a significant predictor of neurological outcome at 6 weeks (P = 0.995, 0.999, 0.994) and at 3 months (P = 0.649, 0.172, 0.883).

Discussion

Demographics

Traumatic cervical spine injury, from this study, has a male preponderance. It is five times more common in males when compared with females, with a mean age of 40.2 ± 15.1. The mean age for males and females in this study was similar (P-value = 0.901). Local and international literatures have also reported male predominance and a mean age ranging between 30 and 37 years.[8,10,11]

Quantitative MRI parameters and neurological profile

The pattern of MSCC, MCC, and LOL showed a general decrease from ASIA A to ASIA E. Patients with ASIA A-type injury had a mean MSCC, MCC, and LOL of 34.3 ± 21.3, 21.4 ± 22.2, and 38.0 ± 36.7, respectively, compared with those of ASIA E: 4.4 ± 4.2, 5.7 ± 9.9, and 0.00 ± 0.00 for MSCC, MCC, and LOL. One-way ANOVA test between MSCC, MCC, LOL and the AIS was not found to be significant on admission in our study [Table 2]. The pattern noticed in this study was similar to that found by Magu *et al.*,[12] who also reported decreasing mean values for all the quantitative MRI parameters from ASIA A to ASIA E. However, ANOVA tests were significant for all the parameters in their study unlike in this study. In our study, ANOVA tests were significant for LOL at 6 weeks and 3 months but not on admission [Table 3]. This may also be related to secondary injury from poor pre-hospital care and transfer modes in our patients, with associated oedema on admission that settles over the period of admission. In their prospective study of patients with traumatic spine trauma, Gupta *et al.*[13] reported the mean MCC, MSCC, and LOL for patients with ASIA E-type injury as 5.0 ± 10.69, 0, and 0, respectively.

On grouping the patients into groups I, II, and III, the mean MSCC, MCC, and LOL were found to progressively decrease from group I to group III [Table 3]. This is in keeping with severity of neurological injury. On admission, the difference in mean of all MRI parameters across groups was not significant at $P < 0.05$. However, as discussed earlier, the mean LOL for respective groups at 6 weeks and at 3 months showed a significant difference with P-values of 0.031 and 0.027 [Table 3]. The MSCC also showed difference which was just short of statistical significance (P = 0.08). From this study, all three quantitative parameters (MSCC, MCC, and LOL) were higher in patients with complete injuries compared with incomplete injuries. These findings corroborate those of Martínez-Pérez *et al.*,[14] who found that complete SCI on admission correlates with the length of intramedullary lesion.

Table 1: Age distribution of patients

Age (years)	Frequency	% Frequency
11–20	5	7.2
21–30	15	21.7
31–40	21	30.4
41–50	9	13.0
51–60	11	15.9
≥61	8	11.6
Total	69	100.0

Table 2: Association between AIS and MRI parameters on admission

Parameters	ASIA A, mean±SD	ASIA B, mean±SD	ASIA C, mean±SD	ASIA E, mean±SD	*P*-value#
MSCC (%)	34.3±21.3	25.4±16.6	22.6±16.4	4.4±4.2	0.089
MCC (%)	21.4±22.2	12.5±10.0	11.1±11.8	5.7±9.9	0.380
LOL (mm)	38.0±36.7	48.9±23.5	26.1±16.5	00.00±0	0.124

Table 3: Association of admission mean quantitative MRI parameters with AIS

MRI parameters	American Spine Injury Association Impairment Scale			*P*-value	Test statistic
	ASIA A	ASIA B–D	ASIA E		
Admission					
MSCC (%)	34.3±21.3	22.8±16.7	6.6±2.5	0.078	ANOVA
MCC (%)	21.4±22.2	11.2±10.2	8.6±12.2	0.242	ANOVA
LOL (mm)	38.0±36.7	38.9±25.3	00.0±00	0.266	ANOVA
6 Weeks					
MSCC (%)	35.7±23.5	29.7±18.6	4.4±4.2	0.081	ANOVA
MCC (%)	22.4±20.5	9.9±10.7	5.7±9.9	0.122	ANOVA
LOL (mm)	57.2±38.9	39.7±25.3	00.0±00	0.031	Kruskal–Wallis
3 Months					
MSCC (%)	41.4±37.6	29.9±20.5	4.4±4.2	0.089	ANOVA
MCC (%)	19.8±30.1	7.0±7.8	5.7±9.9	0.380	ANOVA
LOL (%)	28.1±16.4	41.9±25.0	0.0±0.0	0.027	Kruskal–Wallis

Table 4: Quantitative MRI parameters and grade of AIS on admission, 6th week, and 3 months

Parameters	ASIA Impairment Scale		P-value	Test statistic
	Good*	Poor**		
Admission				
MSCC	4.4±4.2	32.6±24.0	0.032	*t*-test
MCC	5.7±9.9	9.9±15.1	0.235	*t*-test
LOL	0.0±0.0	38.7±23.4	0.000	*t*-test
6 Weeks				
MSCC	3.26±4.1	31.3±20.5	0.000	*t*-test
MCC	4.3±8.6	14.8±17.1	0.15	Wilcoxon W
LOL	3.0±6.0	41.4±31.7	0.006	Wilcoxon W
3 Months				
MSCC	12.4±15.3	36.2±24.8	0.054	*t*-test
MCC	5.7±7.0	11.2±17.0	0.455	*t*-test
LOL	10.5±15.2	44.1±23.2	0.007	*t*-test

*Good AIS: ASIA D and E **Poor AIS: ASIA A, B, and C
t-test: Independent *t*-test

Quantitative parameters and subgroup outcome

Outlook of quantitative parameters was further assessed when patients were re-grouped into those with 'good AIS' and those with 'poor AIS'. Those with ASIA D and E were considered to have good AIS, whereas those with ASIA A, B, and C were considered to have poor AIS. Patients with poor AIS were observed to have higher mean quantitative parameters on admission, at 6 weeks, and at 3 months. MSCC and LOL were significantly higher among patients with poor AIS on admission and at 6 weeks [Table 4]. The MCC was not statistically significant between those with good AIS and those with poor AIS on admission, at 6 weeks, and at 3 months. This is in keeping with the fact that it is the level of cord injury (measured as the MSCC and the LOL) that directly determines the grade of neurological injury. AIS can only be indirectly affected by the mean canal size, which has been shown to be often congenitally narrow among Nigerians in a study by Ndubuisi *et al.*[15] Magu *et al.*[12] have also shown that higher MSCC, MCC, and LOL were associated with poorer outcome among their patients.

Outcome prediction model

On binary logistic regression analysis, none of the MSCC, MCC, and LOL was found to predict good AIS outcome at 6 weeks or at 3 months. However, with decrease in MSCC and LOL values, the odds for having a good outcome (AIS D and E) were 6.3 and 6.6, respectively, at 6 weeks. Consequently, even though these parameters could not predict good or poor AIS outcome, patients with lower MSCC and LOL have a higher likelihood of having a good AIS outcome. This finding differs from that of the study by Miyanji *et al.*,[16] who found MSCC to be predictive of outcome on follow-up. Similarly, another study from Ohio, USA found MSCC and LOL to have a predictive value for neurological outcome in acute cervical traumatic SCI.[17] Some of the factors that could explain the variations in this study when compared with other studies include the use of low tesla MRI in this study (0.35 T), the variation in the timing

of MRI which was placed at within 0–14 days of injury, and the short follow-up duration of just 3 months.

Most studies of quantitative MRI parameters were done with 1.5 T MRI and usually within 72 h of injury.[9,12,13,16-18] These are frequently not achievable in our environment. In the report by Mezue *et al.*[19] from the study area, the average delay before presentation in patients with traumatic cervical injuries was 10.5 days. This study therefore accommodated patients who had MRI within 14 days of injury. Unfortunately, MRI features following traumatic spine injuries have been shown to undergo evolution over couple of weeks post trauma.[20] This and the quality of imaging could lead to understandable variations in all measured parameters, and we acknowledge these as limitations to the study. Additionally, a recent literature review showed that studies with follow-up durations of approximately 6 months or less reported significantly lower recovery rates for incomplete SCI when compared with studies with long-term (3–5 years) follow-ups.[21] With a maximum follow-up period of 3 months post trauma, conditioned by the design of the study, outcome parameters in this study may be limited in depicting the complete picture.

Conclusion

In conclusion, the mean quantitative MRI parameters are higher for complete spinal cord injuries, but the correlation with severity of neurological injury failed to achieve statistical significance overall. High MSCC and LOL significantly correlate with poor AIS at various stages post trauma; however, MCC does not significantly correlate with neurological outcome. Hence, patient-specific MSCC and LOL should be routinely included as adjuncts to AIS in sub-stratification of neurologic severity in T-CSI. Further research needs to be carried out on the neurologic outcome prediction values of quantitative MRI parameters in clinical practice.

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Conflicts of interest

There are no conflicts of interest.

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