■ SPINE

The case for early treatment of dislocations of the cervical spine with cord involvement sustained playing rugby

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The most common injury in rugby resulting in spinal cord injury (SCI) is cervical facet dislocation. We report on the outcome of a series of 57 patients with acute SCI and facet dislocation sustained when playing rugby and treated by reduction between 1988 and 2000 in Conradie Hospital, Cape Town. A total of 32 patients were completely paralysed at the time of reduction. Of these 32, eight were reduced within four hours of injury and five of them made a full recovery. Of the remaining 24 who were reduced after four hours of injury, none made a full recovery and only one made a partial recovery that was useful. Our results suggest that low-velocity trauma causing SCI, such as might occur in a rugby accident, presents an opportunity for secondary prevention of permanent SCI. In these cases the permanent damage appears to result from secondary injury, rather than primary mechanical spinal cord damage. In common with other central nervous system injuries where ischaemia determines the outcome, the time from injury to reduction, and hence reperfusion, is probably important.

In order to prevent permanent neurological damage after rugby injuries, cervical facet dislocations should probably be reduced within four hours of injury.

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Most spinal cord injuries (SCIs) are the result of high-speed road traffic accidents.[1] SCIs arising from Rugby Union are rare[2] and occur at lower speed. Where it has been possible to measure the incidence of such injuries, it appears to have decreased following recent changes in the laws of the game regarding the scrum and the introduction of injury prevention programmes.[3,4] Half of the patients with a SCI sustained during rugby have either a unilateral or bilateral cervical facet dislocation.[5]

The pathophysiology of SCI involves a primary mechanical injury that disrupts axons, blood vessels and cell membranes, followed by a secondary injury involving, among others, oedema, ischaemia, electrolyte shift, free radical production, inflammation and delayed apoptotic cell death.[6] There is no treatment currently available that reduces the effects of the primary injury. Low-velocity injuries such as those sustained in rugby present an opportunity to reduce overall spinal cord damage because first, there is a lesser degree of primary mechanical SCI, and secondly, there is an opportunity to prevent secondary damage from mechanisms such as ischaemia.

The clinical staff of the Conradie Spinal Cord Injury Centre in Cape Town, South Africa, have carried out early reduction of cervical spine dislocations over several decades. This series reports the outcome of one subgroup, namely patients with rugby injuries.

Previous studies of acute traumatic SCI have not demonstrated neurological improvement following spinal cord decompression.[7,8] Trauma centres around the world deal mainly with high-velocity injuries, especially road traffic accidents, where patients often have coexisting polytrauma. This series of rugby-injured patients had specific features, including an isolated spinal injury, a relatively narrow age range of 14 to 47 years, a consistent treatment protocol, an SCI resulting from low-velocity trauma, and reduction of the dislocation within a few hours of injury in many cases.

Patients and Methods

Over a period of 12 years from 1988 to 2000, 113 rugby injuries to the cervical spine were treated at the Conradie Spinal Cord Injuries Centre in Cape Town. All patients were male and 57 had facet dislocations. The remaining patients had some other cervical trauma such as a hyperextension injury, a burst fracture or a tear-drop injury, and were not included in the study. Data collected included demographics, mechanism and timing of injury, time to successful reduction, and Frankel grade[9] (Table I) prior to treatment and at discharge after three to six months.

Table I. Frankel classification[9]

Frankel grade (score*)	
Grade A (1)	No voluntary motor or sensory function below the level of the injury
Grade B (2)	No voluntary motor function but some sensory function below the level of the injury
Grade C (3)	Some voluntary motor and some sensory function below the level of the injury. Motor function not useful
Grade D (4)	Some voluntary motor and some sensory function below the level of the injury. Motor function useful
Grade E (5)	Normal

* for use in the statistical analysis

Table II. The reason for the injury in the 57 patients

Injury reason	**Number (%)**
High tackle	8 (*14.0*)
Tackle	8 (*14.0*)
Tackler	7 (*12.3*)
Collided/ruck collision	2 (*3.5*)
Ruck	9 (*15.8*)
Scrum collapse	19 (*33.3*)
Scrum ramming	3 (*5.3*)
Loose scrum	1 (*1.8*)

All were admitted directly to the intensive care unit, where initial assessment included a neurological examination, Frankel grading, radiographs of the cervical spine and monitoring of heart rate, oxygen saturation and blood pressure. They were treated according to a protocol. After radiological confirmation of the dislocation, fluoroscopy was subsequently performed and Cone's callipers were inserted. The patient was strapped to a Stoke Mandeville pack bed with a low head pack, which enabled cervical traction to be applied in sufficient neck flexion to enable the facets to be unlocked and to facilitate subsequent neck extension. Analgesia and muscle relaxation were achieved using titrated intravenous morphine and diazepam. The patients remained awake, conscious, and able to communicate any neurological change. Scans were not obtained during this process, as this might have produced unnecessary delays in reduction. As the importance of timely reduction in producing a better neurological outcome became apparent early in the series, plain radiographs were replaced by fluoroscopy to achieve even faster reduction.

Rapid closed reduction was performed using 10 lb increments of traction, under fluoroscopic control, until reduction was achieved.[10] Clinical reassessment preceded each weight increment to ensure no deterioration in clinical or neurological status. The median weight required to achieve reduction was 81 lbs (30 to 160). The facets often reduced with an audible or palpable click. Once reduction was achieved, the neck was put into moderate extension and the traction weight was reduced to 7 lb to 10 lb. This protocol enabled reduction within about ten minutes in all but two patients. No complications occurred.

Statistical analysis. Data were analysed using the SPSS version 15.0 (SPSS Inc., Chicago, Illinois). Simple descriptive statistics were used to describe patient characteristics: n (%) for categorical data, median with range and interquartile range (IQR) for non-normally distributed continuous data, and mean with standard deviation (SD) for normally distributed continuous data. Assessment of distribution of the data was determined using simple visual methods and formal Shapiro-Wilk tests. The two continuous variables of age and reduction delay time were found to be non-normally distributed and, if required for the analysis, were either rank transformed or divided into (unbiased) quartiles as appropriate. The statistical significance of associations between categorical variables was assessed using the chi-squared test (with continuity correction for 2 × 2 tables and testing for linearity in larger tables), and the Mann-Whitney U and Kruskal-Wallis tests were used to compare abnormally distributed data between two or more than two groups, respectively. Associations between abnormally distributed continuous variables were assessed using Spearman's correlation coefficient (r_s). Receiver operating characteristic (ROC) curves were used to determine the best cut-point (the point closest to the top left of the graph) by comparing the values of sensitivity (percentage of true positives detected by the test) and specificity (percentage of true negatives detected by the test) of all possible cuts. Curves were compared using the area under the curve (AUC), where a perfect test has an AUC of 1.0 and a useless test (no better than chance) an AUC of 0.5. Multiple linear regression analysis was used to determine the statistical independence of effects using *t*-tests of adjusted regression coefficients. Statistical significance throughout was defined as $p < 0.05$. To express the uncertainty in the estimates, 95% confidence intervals (CIs) were used.

Results

Patient demographics and type of injury. The 57 male patients had a median age of 22 years (14 to 47, IQR 18 to 27). When divided at the quartiles, 15 patients were aged 14 to 18 years, 15 were 19 to 22 years, 14 were 23 to 27 years, and 13 were 28 to 47 years.

Of the facet dislocations, 34 were bilateral and 23 were unilateral. The level of the dislocation was C3/4 in five patients, C4/5 in 22, C5/6 in 24 and C6/7 in six.

The events in the game associated with the dislocation are shown in Table II.

Severity of neurological injury at admission and at discharge. The admission and discharge status of each patient is shown in Figure 1.

Prior to facet reduction, the Frankel grade was A in 32 patients, B in 11, C in nine and D in five.

The Frankel grades on admission and at discharge were significantly associated, with the grade at discharge

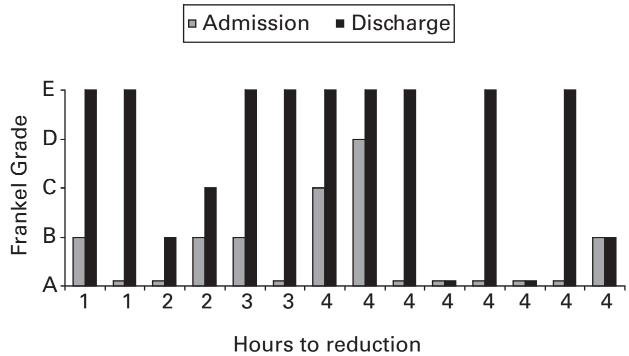

Fig. 1a

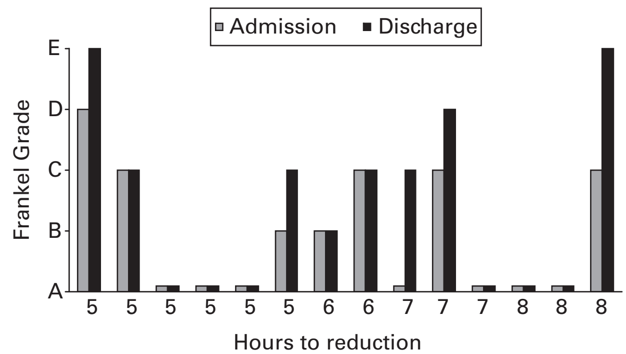

Fig. 1b

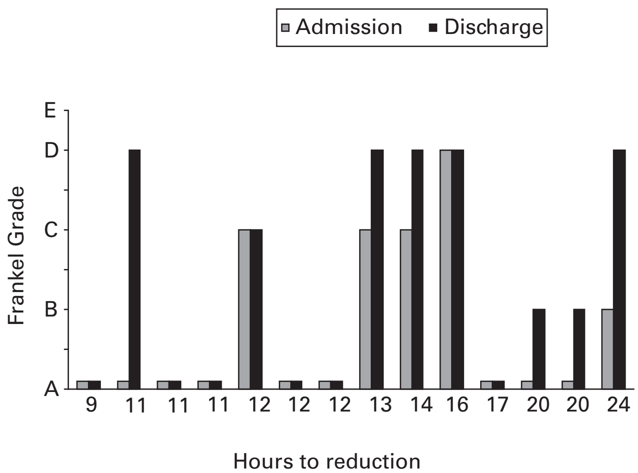

Fig. 1c

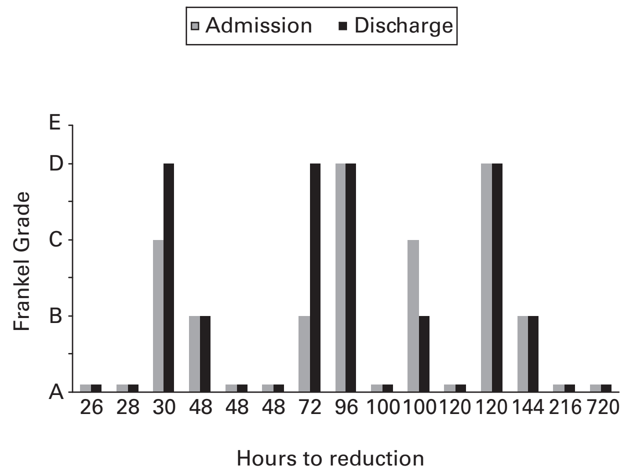

Fig. 1d

Histograms showing Frankel grades on admission compared with those at discharge for patients whose dislocations were reduced within the four quartiles of time from injury: a) for the 14 patients reduced within four hours of injury; b) for the 14 patients reduced between five and eight hours of injury; c) for the 14 patients reduced between nine and 25 hours of injury; and d) for the 15 patients reduced between 26 hours and one month of injury.

Table III. Frankel grade on admission compared to discharge. Data are shown as number (row %) unless otherwise indicated

		Admission grade					
		A	**B**	**C**	**D**	**E**	**Total**
Admission grade	A	22 (*69*)	3 (*9*)	1 (*3*)	1 (*3*)	5 (*16*)	32 (*56.1*)
	B	0	5 (*46*)	2 (*18*)	2 (*18*)	2 (*18*)	11 (*19.3*)
	C	0	1 (*11*)	2 (*22*)	4 (*44*)	2 (*22*)	9 (*15.8*)
	D	0	0	0	3 (*60*)	2 (*40*)	5 (*8.8*)
	E	0	0	0	0	0	0
	Total	22 (*38.6*)	9 (*15.8*)	5 (*8.8*)	10 (*17.5*)	11 (*19.3*)	57

being the same or improved, generally by almost one grade, in all but one patient (chi-squared test for linear trend = 1.34, degrees of freedom (df) = 1, p = 0.25) (Table III).

At discharge 11 patients were Frankel grade E (normal) and of these, the Frankel grade on admission was A in five, B in two, C in two and D in two. The dislocation in all but two of these 11 patients was reduced within four hours of injury. The two who were reduced after four hours and made a full recovery had at least some voluntary movement on admission. In contrast, of the nine patients who were reduced within four hours of injury and went on to make a full recovery, only two had some voluntary movement on admission.

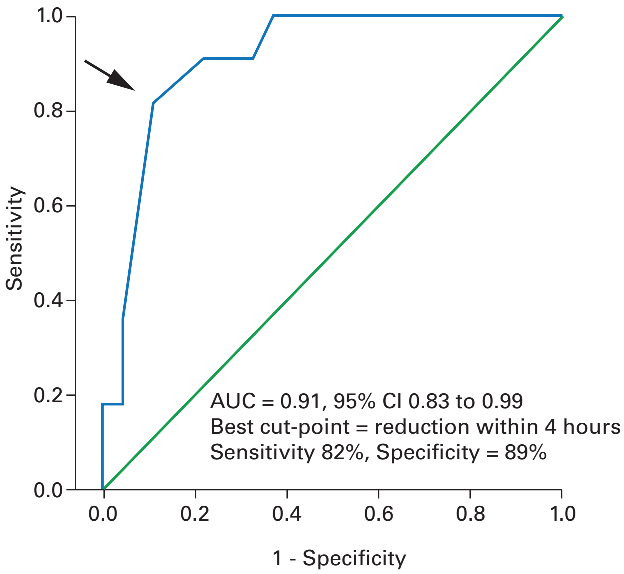

Fig. 2a

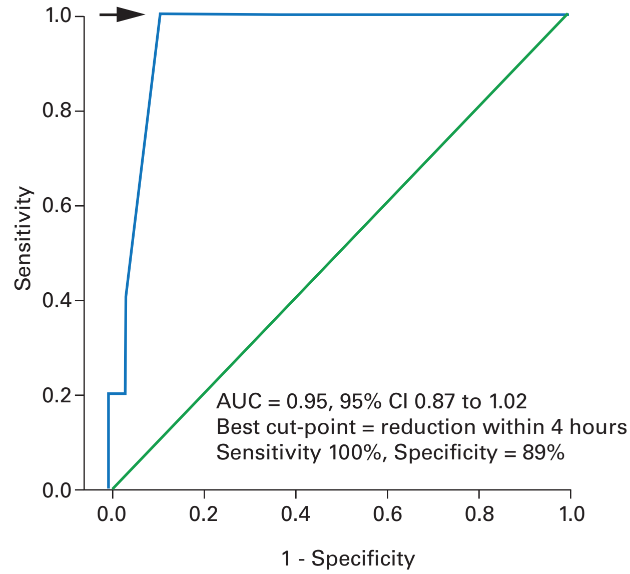

Fig. 2b

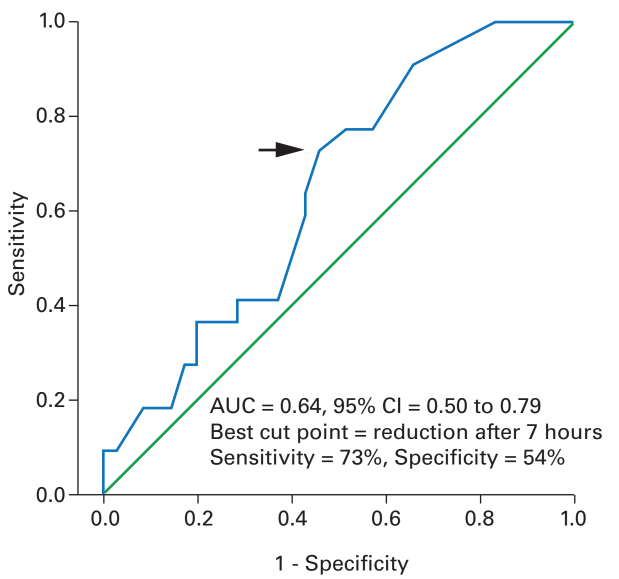

Fig. 2c

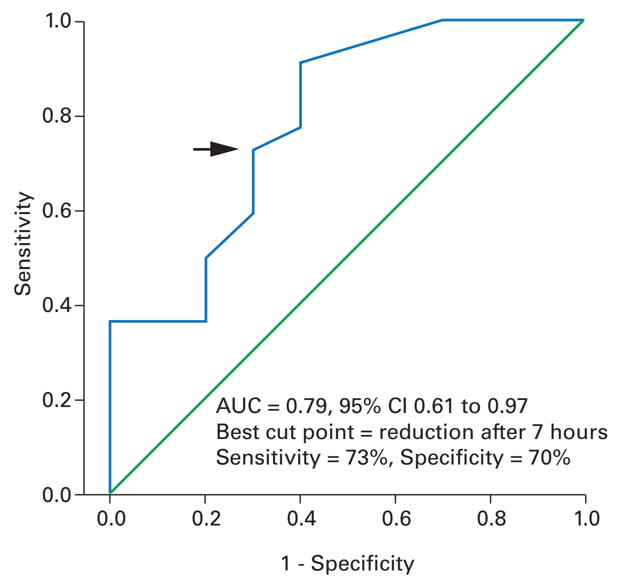

Fig. 2d

Receiver operating characteristics (ROC) curves showing sensitivity against 1-specificity of delay time in determining either complete recovery (Frankel grade E) or complete paralysis (Frankel grade A) at discharge. The arrow shows the 'best cut-point' of delay time at predicting outcome. For complete recovery (both curves) this is four hours and for complete paralysis (both curves) it is seven hours; a) complete recovery at discharge, all patients (n = 57); b) complete recovery at discharge, patients completely paralysed on admission (n = 32); c) complete paralysis at discharge, all patients (n = 57); d) complete paralysis at discharge, patients completely paralysed on admission (n = 32) (AUC, area under curve; CI, confidence interval).

Three patients died while in the unit, one of aspiration pneumonia at nine days post injury and two of pulmonary embolism at three weeks and three months post-injury, respectively. The dislocations were at C4/5 in two patients and at C6/7 in one patient. All three were Frankel A on admission and had shown no improvement prior to death.

Spinal reflexes: spinal shock. The pattern of reflex suppression below the injury was not analysed because of the conclusions of Ko et al,[11] who, in a prospective study of reflex changes after acute traumatic spinal cord injury, found that the absence of reflexes and the recovery of reflexes in a caudal to rostral sequence was of limited clinical use and should be discarded.

Reduction delay. The dislocation in all patients was successfully reduced, with the median time from injury to reduction being nine hours (1 to 720, IQR 4 to 27). Dividing patients into quartiles by time to reduction, 14 were

Table IV. Relationship between time to reduction and Frankel grade (score) on discharge. Data are presented as n (row %)

Delay quartile (hours)	Frankel grade on discharge					
	1	2	3	4	5	Total
0 to 4	2 (*14.3*)	2 (*14.3*)	1 (*7.1*)	0	9 (*64.3*)	14 (*100*)
5 to 8	6 (*42.9*)	2 (*14.3*)	3 (*21.4*)	1 (*7.1*)	2 (*14.3*)	14 (*100*)
9 to 25	6 (*42.9*)	2 (*14.3*)	1 (*7.1*)	5 (*35.7*)	0	14 (*100*)
26 to 720	8 (*53.3*)	3 (*20.0*)	0	4 (*26.7*)	0	15 (*100*)
Total	22	9	5	10	11	57

reduced within four hours, 14 within five to eight hours, 14 within nine to 25 hours, and 15 were reduced between 26 hours and one month of injury.

Association between the time to reduction and the neurological outcome. Although there was no association between the time to reduction and the severity of injury on admission as assessed by Frankel grade (r_s = 0.051, p = 0.71), the time to reduction was negatively associated with the Frankel grade at discharge in that the greater the delay the poorer the outcome (r_s = -0.38, p = 0.004). In terms of delay quartile, eight of the 15 patients with the longest delays remained completely paralysed on discharge, this being true of only two of the 14 patients with the shortest delays (chi-squared test for linear trends = 4.07, df = 1, p = 0.044) (Table IV). Overall, 20 of the 43 patients (46.5%) whose dislocation was reduced after four hours were completely paralysed on discharge, compared with two of the 14 (14.3%) who had been reduced within four hours of the injury (chi-squared test = 3.37, df = 1, p = 0.066).

The association between the time to reduction and complete recovery. The evidence indicates that reduction within four hours is important in determining outcome, with delays longer than this being associated with a worse outcome. Although one patient delayed for five hours increased one level from D to E, and thus achieved complete recovery, three of the eight patients in whom the reduction was delayed by five to six hours remained Frankel A, with the remaining four being either unchanged or improving by only one grade. This compares with only two patients of those successfully reduced within four hours who remained Frankel A (Table III). All five patients who made a full recovery from complete paralysis had been reduced within four hours of injury. In contrast, 20 of the 22 patients who remained completely paralysed on discharge had been reduced after four hours (chi-squared test = 25.2, df = 1, p < 0.001).

ROC analysis confirmed the importance of reduction within four hours in determining complete recovery at discharge. Considering all 57 patients, the best cut-point for complete recovery was a delay between injury and reduction of less than four hours (Fig. 2a). This value of four hours had a sensitivity of 82% and specificity of 89% and an area under the curve (AUC) of 0.91 (95% CI 0.83 to 0.99). The importance of early reduction is further shown by focusing only on the 32 patients who were completely paralysed on admission (Frankel grade A; Fig. 2b): the sensitivity was 100% and specificity 89%, and the AUC 0.95, 95% CI 0.87 to 1.02. The cut-point most likely to predict complete paralysis on discharge is a delay of more than seven hours, both for all patients (Fig. 2c); AUC = 0.64, 95% CI 0.50 to 0.79; sensitivity = 73%, specificity = 54%) and for those initially completely paralysed (Fig. 2d; AUC = 0.79, 95% CI 0.61 to 0.97; sensitivity = 73%, specificity = 70%).

A low and non-significant correlation was found between Frankel grades on admission and at discharge in the patients whose dislocation had been reduced within four hours (r_s = 0.21, p = 0.48). In each of the other three quartiles there was a strong association between admission and discharge scores (r_s = 0.88, p < 0.001; r_s = 0.75, p = 0.002; and r_s = 0.95, p < 0.001 in quartiles 2, 3 and 4, respectively). This contrasts with the weaker overall association (r_s = 0.60, p < 0.001). In other words, in those whose dislocation was reduced within four hours it appears that the early reduction is more important in determining outcome than the Frankel grade on admission.

Independence of the association between the time to reduction and outcome. The association between the time to reduction and outcome may, however, be explained by confounding factors which, by definition, are associated with both the time to reduction delay and the Frankel grade at discharge. Potential confounding factors were considered to be the severity of injury (Frankel grade on admission), date of injury, type of injury (unilateral or bilateral), age, and reason for injury, such as tackling or scrum-related injury. Although there were significant associations between the time to reduction and the type of injury, age and reason for injury, none of these factors was significantly associated with outcome (Frankel score on discharge) and thus none is likely to be strongly confounding. On multiple regression analysis, adjusting for the effects of age, reason for and type of injury, and Frankel score on admission, an independent effect of time to reduction (rank normalised) remained (β = -0.037, SE(β) = 0.010, t = -3.71, p = 0.001), with the greater the delay the worse the outcome (the lower the Frankel discharge score). The association is non-linear, however, with delay after four hours not associated with an increasingly poor outcome: compared to those with a delay of four hours or less (the reference group), those in the other three quartiles had adjusted Frankel discharge scores which were respectively 1.7, 1.6, and 2.0 points lower (i.e. poorer) (all *t*-test p < 0.001).

Surgical fixation. An elective single-level fusion was performed in 50 of the 57 patients, being posterior in 45, anterior in three, and both anterior and posterior in two. The time from reduction to surgery was a median of 5.5 days (0 to 24).

Discussion

This is the largest reported case series of low-velocity cervical spine dislocations resulting from accidents playing rugby and managed by early closed reduction. Patients in this series had a significantly improved neurological outcome if reduction was achieved within four hours of injury.

Neurological outcome after traumatic cervical spinal cord injury is summarised in the review of Kirshblum and O'Connor.[12] Full recovery in patients with complete acute traumatic spinal cord injury is rare.[13] The usual time to reduction after application of the callipers of about ten minutes in this series was faster than the 21 minutes (5 to 65) reported by Lee, MacLean and Newton,[10] probably owing to the absence of bony and other injuries, such as in road traffic accidents, and the use of fluoroscopy to monitor reduction. Reduction was also more frequently achieved.

There is growing evidence that restoration of blood perfusion within the first four hours of central nervous system injury is important in determining neurological outcome.[14-17] The results of this study provide further evidence for this phenomenon. Hacke et al[14] reported that the sooner the recombinant plasminogen activator (rt-PA) is given to stroke patients the greater the benefit, especially when administered within 90 minutes of onset of the stroke. There is benefit up to three hours after the stroke. Because complete or partial vascular recanalisation takes 60 minutes, this emphasizes the importance of the four-hour window. Mendelow et al[15] described 83 patients with supratentorial extradural haematoma, finding that decompression within two hours was associated with good-quality survival. Seelig et al[16] reported on 20 of 366 consecutive patients with brain injury who had severe brain stem dysfunction and an acute subdural mass. Survival was 70% with delay from injury to operation of less than four hours, but only 10% with delay of over four hours.

In a canine experiment five groups of six Beagle dogs had their spinal cords compressed by a circumferential wire to half the diameter of the spinal canal, which was then decompressed by cutting the wires at zero, one, six and 24 hours and one week after injury.[17] The dogs decompressed at 0 and one hour recovered. The rest remained paraplegic.

Dislocation of the cervical spine in rugby causes spinal cord compression and ischaemia, of which the latter is probably the main cause of the spinal cord damage. If the ischaemia is reversed within four hours the spinal cord will recover to a greater degree than with later decompression. After four hours the ischaemic spinal cord injury is probably largely irreversible.

The difference between the damage to the spinal cord in high- and low-velocity trauma may be crucial. Accordingly, this evidence on decompression of the spinal cord within four hours of injury may not be relevant in cases of high-velocity cervical spinal cord trauma.

Some degree of disc damage is a usual accompaniment of dislocation of the cervical spine.[18] Reduction can cause the damaged disc to protrude into the spinal canal and cause compression of the cord.

We think that when reduction is undertaken more than four hours after injury, both CT and MRI should probably precede reduction as they will clarify the degree of bony and soft tissue injury prior to any intervention.

We think that when the patient is still within the four-hour interval after injury a different approach is required. As soon as the diagnosis of dislocation has been made, reduction should be commenced expediently to ensure that it is completed within the four-hour window. Immediately after reduction, an MRI scan should probably be performed to ensure that no disc extrusion with spinal cord compression has been produced. A CT scan, which will clarify the state of the bones, is less urgent.

It is likely that reduction of the dislocation within four hours of injury in other low-velocity SCIs due to causes such as wrestling, gymnastics and horse riding, will have a similar outcome. Systems for transporting such patients immediately to the nearest trauma centre can readily be developed. The position with high-velocity trauma, such as motor vehicle accidents, is much less clear. Not only may the pathophysiology of the SCI be different in high-velocity injury, but the difficulties of achieving decompression within four hours of injury may be much greater.

The extent of the SCI following a dislocation of the cervical spine sustained during rugby is reduced if reduction is achieved within four hours of injury, but not thereafter. In our view the paralysed rugby player should be transported to an emergency centre capable of diagnosing and reducing such dislocations within four hours of injury. Relocation more than four hours after injury will probably not improve the neurological outcome.

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References

1. **Go BK, DeVivo JM, Scott Richards J.** The epidemiology of spinal cord injury. In: Stover SL, DeLisa JA, Whiteneck GG, eds. *Spinal cord injury: clinical outcomes from the model systems.* Gaithersburg: Aspen Publishers, 1995:35-40.
2. **Fuller CW.** Catastrophic injury in rugby union: is the level of risk acceptable? *Sports Med* 2008;38–975.
3. **Quarrie KL, Gianotti SM, Hopkins WG, Hume PA.** Effect of nationwide injury prevention programme on serious spinal injuries in New Zealand rugby union: ecological study. *BMJ* 2007;334:1150–1153.
4. **Silver JR, Stewart D.** The prevention of spinal injuries in rugby football. *Paraplegia* 1994;32:442–453.
5. **Dunn RN, van der Spuy D.** Rugby and cervical spine injuries: has anything changed?: a 5-year review in the Western Cape. *S Afr Med J* 2010;100:235–238.
6. **Rowland JW, Hawryluk GW, Kwon B, Fehlings MG.** Current status of acute spinal cord injury pathophysiology and emerging therapies: promise on the horizon. *Neurosurg Focus* 2008;25:1–17.
7. **Vaccaro AR, Daugherty RJ, Sheehan TP, et al.** Neurologic outcome of early versus late surgery for cervical spinal cord injury. *Spine* 1997;22:2609–2613.

8. **La Rosa G, Conti A, Cardali S, F Cacciola F, Tomasello F.** Does early decompression improve neurological outcome of spinal cord injured patients?: appraisal of the literature using a meta-analytical approach. *Spinal Cord* 2004;42:503–503.

9. **Frankel HL, Hancock DO, Hyslop G, et al.** The value of postural reduction in the initial management of closed injuries in the spine with paraplegia and tetraplegia. *Paraplegia* 1969;7:179–192.

10. **Lee AS, MacLean JCB, Newton DA.** Rapid traction for reduction of cervical spine dislocations. *J Bone Joint Surg [Br]* 1994;76-B;352-6.

11. **Ko HY, Ditunno JF Jr, Graziani V, Little JW.** The pattern of reflex recovery during spinal shock. *Spinal Cord* 1999;37:402–409.

12. **Kirshblum SC, O'Connor KC.** Predicting neurologic recovery in traumatic cervical spinal cord injury. *Arch Phys Med Rehabil* 1998;79:1456–1466.

13. **Marino RJ, Ditunno JF Jr, Donovan WH, Maynard F Jr.** Neurologic recovery after traumatic spinal cord injury: data from the Model Spinal Cord Injury Systems. *Arch Phys Med Rehabil* 1999;80:1391–1396.

14. **Hacke W, Donnan G, Fieschi C, et al.** Association of outcome with early stroke treatment: pooled analysis of ATLANTIS, ECASS, and NINDS rt-PA stroke trials. *Lancet* 2004;363:768–774.

15. **Mendelow AD, Karmi MZ, Paul KS, Fuller GAG, Gillingham FJ.** Extradural haematoma: effect of delayed treatment. *Br Med J* 1979;1:1240–1242.

16. **Seelig JM, Becker DP, Miller JD, et al.** Traumatic acute subdural hematoma: major mortality reduction in comatose patients treated within four hours. *N Engl J Med* 1981;304:1511–1518.

17. **Delamarter RB, Sherman J, Carr JB.** Pathophysiology of spinal cord injury: recovery after immediate and delayed decompression. *J Bone Joint Surg [Am]* 1995;77-A:1042–1049.

18. **Vaccaro AR, Falatyn SP, Flanders AE, et al.** Magnetic resonance evaluation of the intervertebral disc, spinal ligaments, and spinal cord before and after closed traction reduction of cervical spine dislocations. *Spine* 1999;24:1210–1217.