ORIGINAL ARTICLE

Spinal cord injury without radiographic abnormality (SCIWORA) in adults: MRI type predicts early neurologic outcome

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Objectives: The present study aimed to analyse the clinical and neuroimaging features of a consecutive series of adult patients with spinal cord injury without radiographic abnormality (SCIWORA) receiving early magnetic resonance imaging (MRI), and to apply the recently proposed MRI classification system.

Methods: Grade of neurologic impairment at admission and discharge was reported according to the American Spinal Injury Association Impairment Scale (AIS). A detailed analysis and categorisation of the extra- and intramedullary MRI findings was performed, and the relationship between imaging type and neurological outcome was described.

Results: Twenty-six adult patients (17 male and 9 female) with SCIWORA were identified (mean age of 52 years). The distribution of the initial AIS grade was 8% A ($n=2$), 19% B ($n=5$), 31% C ($n=8$) and 42% D ($n=11$) at admission and 15% ($n=4$) C, 58% ($n=15$) D and 27% ($n=7$) E at discharge, respectively. Type I SCIWORA was found in 23% ($n=6$) and type II in 77% ($n=20$) (IIa: 0%, IIb: 25%, IIc: 75%). The mean improvement of AIS grade in patients with type I lesions was 1.5 (median 1, range 1–3) and 0.9 (median 1, range 0–3) in type II.

Conclusion: The findings underline the prognostic role of early MRI for adult patients with SCIWORA and support the use of the recently introduced MRI classification system.

Level of evidence: Prognostic study, level III.

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INTRODUCTION

Traumatic spinal cord injury (SCI) describes neurological impairment caused by blunt or penetrating trauma to the spinal cord and the surrounding soft and osseous tissues. In majority of the patients with SCI, lesions to the spinal column (that is, fractures and dislocations) are detected by conventional radiographs or computed tomography (CT). However, a subpopulation of patients presents with a clinico-radiological mismatch, previously termed spinal cord injury without radiological abnormality (SCIWORA).¹ Although the introduction of magnetic resonance imaging (MRI) allowed the visualisation of spinal soft-tissue lesions and intramedullary abnormalities, there remained a significant fraction of patients presenting with a discrepancy between neurological impairment and detectable MRI findings.^{2–4} Furthermore, the prognostic value of extra- and intramedullary MRI findings in traumatic SCI presents an ongoing matter of debate.^{3,5} To further improve the interpretability and comparability of MRI findings in patients with a clinico-radiological mismatch, an MRI-based classification system has been introduced.^{4,6}

The present study aimed (1) to further characterise the clinical features of adult patients presenting with SCIWORA, (2) to apply the MRI classifications system in a consecutive cohort and (3) to

assess its prognostic value in the prediction of the early neurological outcome in this population.

PATIENTS AND METHODS

For the present study, SCIWORA was defined as traumatic SCI with neurological impairment at admission to the hospital and exclusion of major fractures or dislocations to the spine; minor osseous lesions without a relation to the neurological affected region were not excluded (that is, fracture of a transverse process).

The hospital information system (HIS; ORBIS, Agfa Healthcare GmbH, Bonn, Germany) of a university hospital in central Europe was retrospectively searched for patients with traumatic spinal cord injuries. The HIS was implemented in 2005, and the search included the period from 1 January 2005 to 1 July 2014. Identification was based on the 10th edition of the International Statistical Classification of Diseases and Related Health Problems German modification (ICD-10). The codes S14.*, S24.*, S34.* and T09.3 were searched. Inclusion criteria were adult patient at admission (age ≥ 17 years) with mature skeleton, traumatic SCI, radiograph and/or CT and MRI of the spine. Exclusion criteria were age <17 years or immature skeleton, non-traumatic SCI, non-existent or missing radiograph and/or CT and/or MRI of the spine, incomplete clinical data, fractures or dislocations of the spine (Figure 1).

For all included patients, the following data were extracted: case number, patient ID, name, sex, date of birth, age at admission, date of admission and discharge, trauma mechanism, length of inpatient stay, duration of ventilation,

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Figure 1 Flow chart depicting the inclusion and exclusion process.

Table 1 Classification of MRI types in adult patients with SCIWORA

MRI type	MRI finding
Type I	No detectable abnormalities
Type IIa	Intraneural abnormalities
Type IIb	Extraneural abnormalities
Type IIc	Extraneural and intraneural abnormalities

Abbreviations: MRI, magnetic resonance imaging; SCIWORA, spinal cord injury without radiological abnormality.
Adapted from Boese and Lechler.⁴

therapeutic interventions, American Spinal Injury Association Impairment Scale (AIS) at admission and discharge, modified Frankel score at admission and discharge, time to MRI (in days) and available outpatient follow-up data.

Patients were treated with physiotherapy during their hospital stay on a daily basis depending on their individual needs. Those with inability to walk at discharge were transferred to neuro-rehabilitation facilities.

MRI and classification of MRI patterns

In 21 patients, MRI scans were stored in a picture-archiving and communication system (IMPAX, AGFA HealthCare GmbH, Bonn, Germany). In five patients, MRI data were available as print. MRI scans were analysed following a standardised protocol. Intramedullary findings were classified as either oedema or haemorrhage in sagittal T1- and T2-weighted MRI images: oedema was defined as hyperintense T2 signals (central and peripheral) and normal T1 signal; haemorrhage was defined as inhomogenous T1 and hypointense (central) T2 signals with a rim of hyperintense rim.⁷ Extramedullary findings were classified as stenosis, intraspinal and prevertebral haematoma, injury to the spinal ligaments and minor fractures. Finally, the MRI type was classified according to Boese and Lechler (Table 1).⁴ Sagittal T1-weighted, T2-weighted and Short Tau Inversion Recovery sequences were available for analysis in all patients. Images were acquired using five MRI machines (1.5 Tesla Philips Medical Systems, Philips GmbH Market DACH Healthcare, Hamburg, Germany; Intera ($n=19$), Ingenia ($n=2$) and Achieva ($n=4$); 1 Tesla Philips Medical Systems Panorama HFO, Philips GmbH Market DACH Healthcare ($n=1$)).

Statistics

Statistical analysis was performed using IBM SPSS Statistics 22 (IBM Corporation, Armonk, NY, USA). Descriptive analysis included the presentation of absolute mean values and ranges of the measured variables. AIS grades were transformed into numbers (A = 1, B = 2, and so on), means and medians and ranges were given.

Ethics

The study protocol followed the Declaration of Helsinki and was approved by the local ethics committee (14–162). Because of the retrospective study design, no informed consent was necessary.

RESULTS

Demographic and clinical characteristics of adult patients with SCIWORA

A total of 26 (17 male and 9 female) adult patients with SCIWORA with a mean age of 52 years (range: 17–80) and a mean inpatient stay of 11.3 days (range: 2–37) were included. Type I SCIWORA had a mean length of hospital stay of 3.3 days (range: 2–6; s.d. 2.1) compared with type IIb and IIc with means of 12 days (range: 2–18; s.d. 6.6) and 14.8 days (range: 3–37; s.d. 10.1), respectively.

The detailed demographic and clinical characteristics of the cohort are shown in Table 2. The mean delay to spinal MRI imaging was 1.2 days (range: 0–11 days); twenty patients received MRI within 24 h, one within 48 h, three within 3 days, one within 5 days and one patient 11 days following the trauma. CT before MRI was performed in 21 patients. Nine patients were monitored on ICU, and four patients needed mechanical ventilation for a mean time of 7.5 days (range: 1–21). Eighteen patients received intravenous corticosteroids and eight patients were treated surgically. In seven patients, a cervical orthosis was employed.

Table 2 Clinico-demographic data of 26 adult patients with SCIWORA

ID	Sex	Age (years)	Trauma mechanism	Time to MRI (days)	Hospital stay (days)	ICU stay (days)	Ventilation (days)	Cervical collar	Corticosteroids	Surgery	Intradural oedema	Spinal stenosis	OPLL	Spondylolisthesis	Spondylolysis	Disc bulging	Flavum bulging	MRI type
1	m	29	Fall	1	2			No	No	No	No	No	No	No	No	No	No	1
2	m	66	Fall	0	3; 23 ^a			No	Yes	Yes ^a	Yes	Yes	No	Yes	Yes	Yes	Yes	2c
3	m	18	FFH	1	2			No	Yes	No	No	No	No	No	No	No	No	1
4	f	75	Fall	0	21	21	21	No	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	2c
5	m	17	Fall	0	2			No	Yes	No	No	No	No	No	No	No	No	1
6	m	76	Fall	3	23	24	7	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	2c
7	m	61	RTA	1	13	9		Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	2c
8	f	22	RTA	0	6			No	Yes	No	No	No	No	No	No	No	No	1
9	f	61	Fall	1	14			Yes	No	No	No	Yes	No	Yes	No	No	Yes	2b
10	f	70	Fall	0	27	3		No	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	2c
11	m	43	RTA	0	18	14		No	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	2c
12	m	65	Fall	5	7			No	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	2c
13	f	36	RTA	0	9	1	1	No	Yes	No	No	Yes	No	No	No	Yes	No	2b
14	f	62	Fall	0	12			No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	No	2c
15	m	47	RTA	3	6			No	Yes	No	No	No	No	No	No	No	No	1
16	m	61	FFH	0	6			No	No	No	Yes	Yes	No	No	Yes	Yes	Yes	2c
17	m	67	Fall	11	17			No	No	No	No	Yes	No	No	Yes	Yes	Yes	2b
18	m	73	Fall	2	7			Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	2c
19	f	22	FFH	1	2			No	Yes	No	No	No	No	No	No	No	No	1
20	m	59	Fall	0	2			No	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	2b
21	f	76	Fall	0	37	8	1	Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes	2c
22	m	43	Fall	0	18			No	Yes	No	No	Yes	No	No	No	Yes	No	2b
23	m	47	FFH	1	14			Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	2c
24	f	38	FFH	0	4			No	No	Yes	Yes	Yes	No	No	No	Yes	No	2c
25	m	46	Fall	0	5			No	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	2c
26	m	80	Fall	0	10			No	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	2c

Abbreviations: f, female; FFH, fall from height; ID, patient identification number; m, male; MRI, magnetic resonance imaging; OPLL, ossification of the posterior longitudinal ligament; RTA, road traffic accident; SCIWORA, spinal cord injury without radiological abnormality.

^aPatient admitted for secondary surgery after the primary stay.

Figure 2 Neurologic impairment at admission and at discharge of adult patients with SCIWORA assessed by AIS. Distribution of AIS at admission (z axis) relative to distribution of AIS at discharge (x axis).⁴

Neurologic impairment

All included patients presented with a cervical SCI. Neurologic impairment at admission and at discharge is shown in Figure 2 and Table 3.

MRI findings and classification of imaging type

The detailed analysis of the observed MRI findings is given in Table 4. In three patients, five minor fractures not related to the SCI were observed (one spinal process fracture, one minimal anterior column impression and three transverse process fractures). Fifty-eight percent ($n=15$) patients presented with intramedullary oedema, whereas no bleeding, contusion or transection was found. Patients were grouped into MRI types according to the following:⁴ type I was found in 23% ($n=6$) and type II in 77% ($n=20$) (IIa: 0%, IIb 25%, IIc 75%).

Relation between MRI type and neurologic impairment

The relation between AIS and imaging type is shown in Figures 3a–d. The mean improvement of AIS grade in patients with type I lesions was 1.5 (median 1, range 1–3) and 0.9 (median 1, range 0–3) in type II. Although type IIb improved by 1.4 (median 2, range 0–2), type IIc was associated with a mean increase of 0.7 AIS grades (median 1, range 0–3). All eight patients who received surgical decompression presented with SCIWORA type IIc.

DISCUSSION

The diagnostic and therapeutic approach to adult patients with SCI presenting with a clinico-radiological mismatch remains to be an ongoing challenge to our field.⁴ Although early MRI has been shown to influence treatment decisions in patients with SCI without major fractures or dislocations,⁸ there remains a paucity of knowledge regarding its role in the prognostication of the neurological outcome. To further improve the reliability and comparability of MRI findings in patients with SCIWORA, a classification system has been introduced recently.^{4,6} In contrast to the previously reported grading systems limited to either extramedullary⁹ or intramedullary MRI abnormalities,¹⁰ the recent classification system accounts for both locations and for cases without detectable MRI findings.⁴ Here, imaging type I was defined as a normal MRI scan, whereas type II comprises three pathological subtypes (see Table 1). Although this classification system has been successfully used to analyse pooled data from publications reporting on paediatric and adult SCIWORA,^{4,6} its prognostic value and real world applicability have not been tested yet.

Table 3 Individual courses of 26 adult patients with SCIWORA including AIS grade and the modified Frankel scale

ID	Neurolog. status at admission		Neurolog. status at discharge	
	AIS grade	Modified Frankel Scale	AIS grade	Modified Frankel Scale
1	C	C	E	E
2	C	C	D	D1
3	C	C	D	D2
4	C	C	C	C
5	D	D3	E	E
6	A	A	D	D1
7	C	C	C	C
8	A	A	D	D2
9	D	D1	D	D2
10	C	C	D	D2
11	B	B	C	C
12	D	D2	D	D2
13	B	B	D	D1
14	D	D1	D	D3
15	D	D2	E	E
16	D	D2	E	E
17	B	B	D	D2
18	D	NA	D	NA
19	D	D3	E	E
20	D	D3	E	E
21	C	C	D	D2
22	B	B	D	D2
23	D	D2	E	E
24	D	D1	D	D2
25	C	C	D	NA
26	B	B	C	C

Abbreviations: AIS, American Spinal Injury Association Impairment Scale; NA, not available; SCIWORA, spinal cord injury without radiological abnormality.

Although a correlation between neurological outcome and MRI pattern has been described previously,^{4,5,11–18} this finding could not be confirmed by others.² The present study reports the existence of a relation between imaging type and neurological outcome in adult patients with SCIWORA. Furthermore, our data support the previously reported superior prognosis of patients presenting with SCIWORA type I (no detectable neuroimaging abnormalities) over patients presenting with type II lesions.⁴ The subsequent analysis of the type II subgroup revealed a higher risk of persistent neurological impairment for patients with combined extra- and intraneural abnormalities (type IIc) compared with those with isolated extraneural abnormalities (type IIb).

In contrast to children with SCIWORA, degenerative changes of the spine and subsequent stenosis to the spinal channel are frequently found in adults presenting with a clinico-radiological mismatch.¹⁹ Importantly, pre-existing spinal stenosis has been proposed to be a risk factor for the development of SCI^{9,20,21} and SCIWORA.⁴ In the analysed population, the detection of extramedullary abnormalities (type II) was associated with an inferior outcome when compared with patients without extramedullary abnormalities. Despite the fact that all surgical interventions were performed in patients with type IIc lesions, this imaging type was associated with a high risk of poor neurological outcome.

Kulkarni *et al.*⁷ described three imaging patterns of intramedullary abnormalities (cord haemorrhage, oedema and mixed type), and their prognostic value has been the focus of a number of reports.^{8,22} In the

Table 4 Surgical therapy in patients with SCIWORA

ID	Sex	MRI type	Operation
2	m	2c	Corpectomy and ventral stabilisation with plate and autologous bone graft
4	f	2c	Corpectomy and ventral stabilisation with plate and autologous bone graft
7	m	2c	Corpectomy and ventral stabilisation with plate and autologous bone graft and cage implantation
18	m	2c	Corpectomy and ventral stabilisation with plate and cage implantation
21	f	2c	Primary: dorsal decompression; secondary ventral plate fixation
23	m	2c	Corpectomy and ventral stabilisation with plate and cage implantation
24	f	2c	Ventral disectomy, decompression and cage implantation with ventral plate fixation

Abbreviations: MRI, magnetic resonance imaging; SCIWORA, spinal cord injury without radiological abnormality.

Figure 3 (a–d) Distribution of AIS at admission and at discharge final relative to MRI type.⁴ (a) Type I. (b) Type II. (c) Type IIb. (d) MRI IIc.

present study, the detection of intramedullary abnormalities was limited to oedemas, whereas no haematomas could be found. The presence of an intramedullary oedema in combination with an extramedullary finding was associated with a poorer neurologic outcome compared with patients presenting with an isolated extramedullary finding and those without any detectable neuroimaging abnormalities.

The treatment in SCIWORA is still based on individual decisions and includes conservative and operative options. In our cohort, surgical procedures were performed in type IIc SCIWORA only. No case of type I or type IIb received surgery. The surgery was indicated on an individual basis, and only patients with spinal channel stenosis and myelopathy signals on MRI were operated on. The types of

surgery were ventral approaches to the cervical spine in 7/7 cases (one operated on during a secondary hospital stay). One patient received dorsal decompression with laminectomy in the first operation and secondary ventral plate fixation; this patient had the longest hospital stay of 37 days including 8 days in the ICU. Interestingly, the mean age of surgical patients was 62.3 years (range 38–76) contrasting 46.9 years (range 17–76) in the conservative group. The use of corticosteroids was based on individual decisions of the treating surgeons and neurosurgeons. Seventeen patients received varying doses of corticosteroids. Of these, three underwent surgery. The application of cervical collars was inhomogeneous. Five of seven surgically treated patients received collars for the post-operative phase, whereas only two patients with a conservative approach were treated with cervical collars.

The authors are aware of the limitations of this report:

First, our findings are based on a retrospective study design and should be confirmed by future prospective observational investigations. However, because of the overall low incidence rate of adult SCIWORA, we recommend a prospective multicentre study of cases presenting with a clinico-radiological mismatch following SCI.

Because of the lack of a consistent rationale determining the choice between surgical or non-surgical treatment and the inhomogeneous application of corticosteroids, our results cannot provide guidance on the therapeutic management of adult patients with SCIWORA.

Furthermore, our study does not include long-term follow-up data, thus limiting the interpretability of the presented outcome data.

Importantly, the study was performed in central Europe, thus limiting the transferability of our findings to populations with different ethnic backgrounds. Consequently, the imaging features of the reported cohort are in contrast to recent reports on Asian adult patients with SCIWORA, with high prevalence rates of ossification of the posterior longitudinal ligament.²³

Next, although high-field MRI scanners and specialised sequences might provide additional information on intra- and extramedullary pathologies in patients with SCIWORA,²⁴ this study was restricted on widely available MRI technology and standard sequences.

The major strength of the present study is its large number of the included adult patients with SCIWORA, as well as the thorough analysis and detailed presentation of the neurologic and imaging characteristics resulting in an excellent reproducibility and interpretability of our data.

Finally, the application of the classification system allowed the reliable assessment of the correlation between neurologic impairment and imaging abnormalities in adult patients with SCIWORA.

CONCLUSION

The findings of our study underline the prognostic role of early MRI for adult patients with SCIWORA and support the application of the recently introduced MRI classification system.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

CKB and RB performed data collection, CKB, RB and PL contributed to data analysis, CKB and PL wrote the manuscript, JD, RB, PE, BK, HCL and PL interpreted the data and critically reviewed the manuscript, all authors read and approved the final version of the manuscript.

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