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Incidence of discoligamentous injuries in patients with acute central cord syndrome and underlying degenerative cervical spinal stenosis

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ABSTRACT

Introduction: Surgical treatment for CCS in patients with an underlying cervical stenosis without instability remains controversial.

Research question: The aim was to assess the incidence of concomitant discoligamentous injury (DLI) in patients with CCS and underlying degenerative cervical spinal stenosis and to determine the sensitivity of MRI by comparing intraoperative site inspection to preoperative imaging findings.

Material and methods: We performed a retrospective analysis of our clinical prospective database. Fifty-one patients (39 male, 12 female) between January 2010 and June 2019 were included. Age, sex, neurological deficits, preoperative MRI, and surgical treatment were recorded. Sensitivity was determined by the quotient of patients in whom all levels of DLI were correctly identified on MRI and the total number of patients with intraoperatively confirmed DLI.

Results: Mean age at surgery was 64.1 ± 11.3 (range 41–86). DLI was suspected in 33 (62.1%) patients based on MRI findings, which could be confirmed intraoperatively in 29 patients (56.9%). In 2 patients, DLI was detected intraoperatively that was not suspected in preoperative MRI; in 5 patients, another level was affected intraoperatively than was indicated by MRI. The overall specificity and sensitivity of preoperative MRI imaging to identify discoligamentous lesions of the cervical spine was 73% and 79%, respectively.

Discussion and conclusion: The incidence of DLI in patients with traumatic CCS based on preexisting spinal stenosis was 60.78%, which is higher than previously reported. The sensitivity of MRI imaging to detect DLI of 79% suggests that these patients are at risk of missing traumatic DLI on imaging.

1. Introduction

Traumatic central cord syndrome (CCS) is the most common form of incomplete spinal cord injury, which can have multiple different underlying pathologies. The clinical presentation is characterized by a motor deficit affecting the upper extremities more than it does the lower extremities as well as variable sensory, bowel, and bladder symptoms. It typically occurs in elderly patients (>60 years) experiencing from an, often asymptomatic, underlying cervical spondylosis and spinal stenosis who have sustained a hyperextension injury often in the setting of a comparatively mild trauma (Molliqaj et al., 2014). In contrast, CCS in younger patients without degenerative alterations in the cervical spine is more likely to be associated with severe, high-energy trauma and concomitant bony or discoligamentous injury (DLI) leading to spinal instability. The presumed pathological mechanism is acute compression of the spinal cord between a thickened ligamentum flavum and an ostophyte or intervertebral disk at the moment of hyperextension due to a lack of sufficient CSF space to protect the spinal cord (Wilson et al., 2020). Secondary, a complex response occurs that is not yet fully understood and includes swelling, edema, an inflammatory response, and neuronal cell apoptosis (Wilson et al., 2020).

Optimal treatment of acute CCS is still the subject of controversial discussions (Chen et al., 2009; Tator et al., 1999). Given that the natural history often shows spontaneous recovery of neurological deficits, the

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recommendation for the management of CCS without associated instability has for a long time been conservative treatment by early immobilization of neck and ICU care to maintain a blood pressure >85 mmHg (Schneider, 1960; Chen et al., 1998). Today, surgical treatment of CCS in patients with proven instability due to fracture or due to acute disc herniation is widely accepted, whereas the management of patients with an underlying cervical stenosis without instability as well as the surgical timing for decompression remains controversial (Park et al., 2015; Divi et al., 2019). In consideration of the pathophysiological mechanism, a consensus has emerged among the majority of neurosurgeons for early surgical decompression with the aim of restoring perfusion to the injured cord and avoiding secondary damage potentiated by local compression-induced ischemia (Wilson et al., 2020). Numerous studies have been conducted addressing the optimal timing of surgery (Samuel et al., 2015; Loibl et al., 2016). Leneham et al. concluded that in the presence of less severe neurologic impairment and a stable spondylotic cervical spine without acute DLI, surgery should be preferred at a later time (Lenehan et al., 2010). Early surgery was recommended in patients with neurologic deficits due to unstable injuries. Recording Guest et al. for patients with spinal stenosis or spondylosis, early surgery was safe but did not improve motor outcomes compared with late surgery (Guest et al., 2002). Fehlings et al. performed a systematic review of studies addressing the question of optimal timing of surgery. He reported relevant heterogeneity in study results, ranging from statistically significant and clinically meaningful improvements to marginally significant improvement or no significant difference after early decompression (Fehlings et al., 2017). Nevertheless, despite low-quality evidence, they suggest that early surgery should be considered as a treatment option in adult patients with traumatic CCS (Fehlings et al., 2017).

Although CT of the cervical spine is the imaging modality of first choice for initial evaluation of cervical trauma in the emergency setting (Yelamarthy et al., 2020), MRI is considered the most reliable imaging modality for clinical or radiological suspicion of traumatic DLI, including the anterior longitudinal ligament (ALL), posterior longitudinal ligament (PLL), or intervertebral discs (Onoue et al., 2019; Henninger et al., 2020; Kumar and Hayashi, 2016; Geck and Wang, 2001).

However, clinical experience shows cases in which no lesion is seen by the radiologist but is detected during surgery. Few studies report direct comparisons between preoperative imaging and intraoperative findings (Malham et al., 2009a, 2009b; Goradia et al., 2007a, 2007b; Henninger et al., 2020; Zhuge et al., 2015). The reported sensitivity in these studies, which are inhomogeneous in their study design and evaluation values, ranged from approximately 48%–100% for ALL and from 50% to 93% for PLL injury (Malham et al., 2009a; Henninger et al., 2020; Zhuge et al., 2015; Goradia et al., 2007a).

We recently performed a retrospective analysis of a similar patient cohort considering all patients who underwent surgical treatment of the cervical spine via an anterior approach after trauma between June 2008 and April 2018 with the aim to compare intraoperative site inspection to preoperative imaging findings and to identify radiological features of patients at risk for under- or overestimation of DLI (Janssen et al., 2021). A discrepancy between imaging and surgical findings was revealed in 14 patients, leading to an overall specificity and sensitivity of preoperative imaging to identify DLI of the cervical spine of 100% and 77.4%, respectively. The results revealed an increased risk of missing detection of traumatic DLI of the cervical spine in MRI imaging in patients with preexisting degenerative cervical spondylosis (Janssen et al., 2021).

When taking into account that MRI is less sensitive, especially in the presence of underlying spondylosis, underdiagnosis of DLI may occur, especially in elderly patients with CCS who have underlying degenerative cervical stenosis. Contrary to the general assumption that bony and DLI are rare in patients with CCS without fractures or signs of instability on the initial CT scan, Krappinger et al. found DLI in 22 of 23 patients, whereas in 3 cases, instability was detected only intraoperatively and was not described by an experienced MRI radiologist (Krappinger et al., 2019).

With this in mind, the aim of this study was to correlate intraoperative situs inspection with preoperative imaging findings in patients with CCS who have underlying cervical stenosis and spondylosis in order to assess the incidence of concomitant discoligamentous injury (DLI) and to determine the sensitivity of MRI in these patients.

2. Material and methods

2.1. Ethical approval

The study was conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki and its later amendments (Helsinki) and was approved by the local ethics committee of the technical university of Munich TUM (5625-12) (GAotWM, 2014).

2.2. Study design and patient inclusion

We performed a retrospective analysis of our clinical prospective database at a large university hospital. All patients who underwent surgery for traumatic cervical spine injury between January 2010 and June 2019 were identified and retrospectively analyzed. Out of 211 patients, 51 met the following inclusion criteria: surgery for traumatic CCS, preexisting spinal stenosis, preoperative T2-weighted and short tau inversion recovery (STIR) MRI sequence and CT scan, and availability of information about intraoperative findings (surgical reports and intraoperative situs documentation). Patients who did not meet the abovementioned criteria or showed relevant motion artifacts in imaging data were excluded. Furthermore, age, sex, and neurological deficits were recorded for each patient.

2.3. Surgery

Neurologic impairment—as measured by the American Spinal Injury Association's Impairment Scale (AIS)—and imaging findings were the determining factors for the indication for surgery. The indication for surgery was generously given in our clinic in case of existing relevant cervical stenosis. The segment with T2 hyperintensity on MRI imaging was decompressed and fused in all cases. All other segments with image-based suspicion of a discontinuity of ALL or injury of the disk were inspected intraoperatively and were decompressed and fused if DLI was confirmed. In case of posterior wall involvement, a posterior approach was performed in a second step. Immobilization was provided by a rigid cervical collar until surgery. 34 patients were admitted to our hospital immediately after the trauma and underwent surgery within 48 h 17 patients were admitted from another primary care hospital or from abroad at a greater distance from the accident and were treated surgically only after more than 48 h. Comparison between early and late operations was not evaluated because of the inhomogeneous cohort.

Surgeries were performed by four different surgeons, all experienced in the treatment of cervical spine injuries. Mean time of surgery was 113.6 min $\pm$ 44.67 min (range 36–240 min).

2.4. Imaging

Imaging diagnostic by CT was performed immediately after arrival of the patient in our clinic. Patients who received initial care at a peripheral hospital had received imaging prior to their hospitalization with us. MRI was performed within 2 h of admission, as MRI is available 24 h at our institution and is obligatory in our protocol in the case auf a central cord syndrome. The MRI imaging did not delay treatment.

2.5. Computed tomography

Imaging by CT was performed either in the context of a polytrauma whole-body scan or for dedicated assessment of the entire dorsal or only the cervical spine. For each protocol, axial (slice thickness of 1 mm) as well as coronal and sagittal (slice thickness of 3 mm) images, centered on the vertebral column, were generated using a bone kernel. CT was performed with a Siemens scanner (Siemens Healthineers, Erlangen, Germany), Philips scanner (Philips Healthcare, Best, and The Netherlands), or Toshiba scanner (Otawara, Japan).

2.6. MR imaging

MRI scans were performed on a 3-T (T) MRI scanner, either Philips Achieva, Philips Ingenia (Philips Medical Systems, the Netherlands B.V.), or Siemens Verio (Siemens Healthcare, Erlangen, Germany). All patients had FLAIR images, high-resolution T1-weighted (w) images, and T2-weighted and STIR MRI sequence.

2.7. Statistics

Statistical analysis including descriptive data analysis was performed using IBM SPSS Statistics version 26.0 (SPSS Inc., IBM Corp., Armonk, NY, USA).

Sensitivity was determined by the quotient of patients in whom all levels of DLI were correctly identified on MRI and the total number of patients with intraoperatively confirmed DLI. Specificity was determined by dividing the number of patients where the absence of DLI were correctly diagnosed on MRI by the total number of patients without DLI confirmed intraoperatively.

3. Results

3.1. Patient characteristics

In total, 51 patients (39 male, 12 female) with a mean age of 64.1 ± 11.3 (range 41–86) at the time of operation met our inclusion criteria. Classified according to the AIS at the time of operation, 3 patients (1.53%) presented with grade E after a temporary neurological deficit directly after the trauma, 18 patients (35.3%) with grade D, 18 patients (35.3%) with grade C, and 6 patients each with grade B or A (each 11.8%). The majority of injuries were caused by low-velocity accidents in 36 (70.6%) cases. Five (9.8%) patients had experienced a high-velocity trauma, 3 (5.9%) a fall from a great height, 6 (11.8%) bicycle falls, and 1 (2.0%) a horse riding accident. All patients were treated with an anterior cervical discectomy and fusion with ventral plating. Three patients received a combined dorsoventral approach due to severe instability from injury to the posterior elements as well. In 1 patient, the decision was made to add a dorsal approach for fixation and decompression after postoperative imaging showed persistent stenosis and hematoma dorsally (Table 1).

3.2. Imaging and intraoperative findings

Preoperative CT scan showed moderate to severe degeneration in all cases. Instability characterized by a traumatic listhesis was seen in 2 cases and a chance-like fracture was observed in 1 patient with diffuse idiopathic skeletal hyperostosis. Other nonrelevant fractures detected by scans were a unilateral fracture of C1 ($n = 1$), fracture of an anterior osteophyte ($n = 5$), fracture of the processus spinosus ($n = 4$) or processus transversus ($n = 1$), and a tear-drop fracture ($n = 2$). In 35 patients, no bony lesion was visible on CT scan.

In MRI imaging, underlying narrowing of the spinal canal was obtained in all patients; image-based spinal cord contusion was present in 44 patients. In 33 (64.7%) cases, MRI showed a suspicion of a cervical DLI, whereas it could only be confirmed intraoperatively in 27 patients. In 26 patients, the localization of the T2 hyperintense signal correlated with the level of DLI confirmed intraoperatively. In 1 case, DLI was detected in the adjacent level of the contusion seen on MRI. In 6 cases, the preoperative suspected DLI (MRI) could not be confirmed intraoperatively (Fig. 1). In 2 patients, intraoperative DLI was obtained although it was not suspected in preoperative MRI (Fig. 3). In 5 patients, further levels were affected intraoperatively than the MRI had indicated (Fig. 2). Segmental instability by DLI was found at C3/4 in 9 cases (31.0%), at C4/5 in 15 cases (51.7%), and at C5/6 in 15 cases (51.7%) (Table 2). Preoperative hematoma was present in 15 patients and was associated with a DLI in 13 cases. Intraoperative findings were evaluated by reviewing the operative report, which mentioned evidence of a lesion of the anterior longitudinal ligament, disc, and/or posterior longitudinal ligament.

When comparing preoperative imaging findings with intraoperative situs inspection, we observed 27 TP, 6 FP, 16 TN, and 2 FN incidences; in 5 cases, an additional affected level was found intraoperatively. The overall specificity and sensitivity of preoperative imaging to identify DLI of the cervical spine was 73% and 79%, respectively. Sensitivity was 93% in cases where a DLI was diagnosed, but an additional level obtained intraoperatively was not considered.

4. Discussion

Our institutional experience comprises 51 consecutive traumatic CCSs and 33 associated image-based cervical DLI. Operative treatment was performed by anterior cervical fusion and ventral plating in 51 consecutive cases in combination with a dorsal approach in 3 cases. To date, this represents the largest case series of surgically treated CCS where a correlation between preoperative imaging and intraoperative detection of DLI was performed. The study results showed a high incidence of DLI in patients with traumatic CCS based on preexisting spinal stenosis. Twenty-nine patients out of 51 (56.9%) showed DLI, which represents a higher incidence than previously reported. Furthermore, 2

Table 1
Demographics and preoperative characteristics.

Demographics % (N) or mean (SD)/median (IR)	Low-velocity (36)	High-velocity (5)	Fall from great height (3)	Fall from bicycle (6)	Fall from a horse (1)	Total (51)
Age	66.9 (±10.12)	57.6 (±13)	59 (±2)	58.3 (±14.3)	50	64.1 (±11.3)
Sex	M 66.7% (24)	M 100% (5)	M 100% (3)	M 100% (6)	M 100% (1)	M 39 (76.5%)
	F 33.3% (12)	F 0	F 0	F 0	F 0	F 12 (23.5%)
Clinical presentation						
Neck pain	25% (9)	20% (1)	66.7% (2)	33.3% (2)	0	27.5% (14)
Brachialgia	5.6% (2)	0	0	0	0	3.9% (2)
Myelopathy	41.7% (15)	60% (3)	66.7% (2)	33.3% (2)	100% (1)	45.1% (23)
Tetraparesis	66.7% (24)	100% (5)	33.3% (1)	33.3% (2)	100% (1)	64.7% (33)
Paresis of upper extremity	91.7% (33)	80% (4)	66.7% (2)	83.3% (5)	0	86.3% (44)
American Spinal Injury Association	A: 16.7% (6)					A: 11.8% (6)
	B: 4.5% (3)	B: 40% (2)	B: 33.3% (1)			B: 11.8% (6)
	C: 41.7% (15)	C: 40% (2)		C: 16.7% (1)		C: 35.3% (18)
	D: 27.8% (10)	D: 20% (1)	D: 33.3% (1)	D: 83.3% (5)	D: 100% (1)	D: 35.3% (18)
	E: 5.6% (2)		E: 33.3% (1)			E: 5.9% (3)

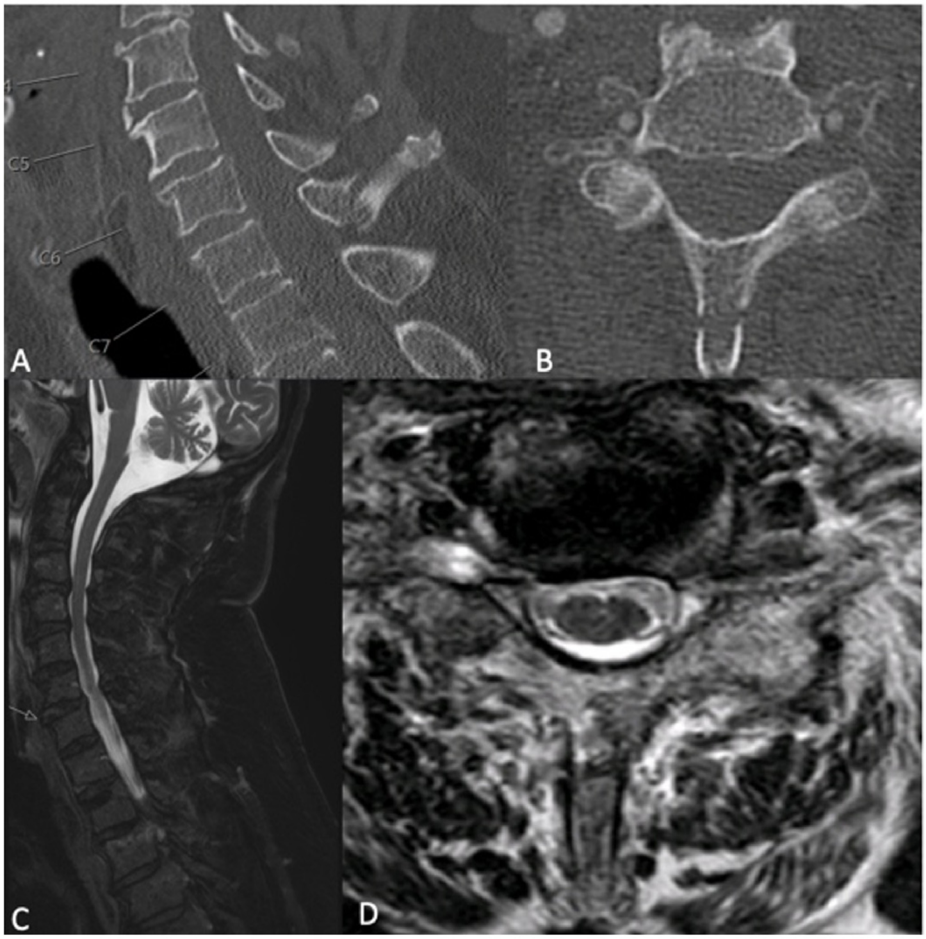

Fig. 1. Example of MRI false positive for DLI: 76-year-old male patient with a spinous fracture of C7 (A,B) in CT scan and a signal enhancement ventrally of the disk of C6/7 in STIR sequences that points to a DLI (C,D). Additionally, a suspected contusion on C3/4 is displayed. However, no DLI could be detected intraoperatively.

patients showed intraoperative DLI without evidence on preoperative MRI. In 5 patients, additional levels were affected intraoperatively than were indicated by MRI. When comparing preoperative imaging findings with intraoperative situs inspection, we observed 27 TP, 6 FP, 16 TN, and 2 FN incidences.

Our results are similar to the findings of Krappinger et al., who obtained hyperextension instability by DLI in 22 of 23 patients experiencing severe traumatic CCS (AIS grade C and worse), whereas in 3 cases, instability was detected intraoperatively and not described by an experienced MRI radiologist in preoperative imaging. Furthermore, they found segmental instability and spinal cord signal at different levels in 2 patients (8.7%), In 8.7% an additional segmental instability was observed in an adjacent segment (Janssen et al., 2021).

In our study, the overall specificity and sensitivity of MRI to identify DLI of the cervical spine was 73% and 79%, respectively. Sensitivity was 93% in the cases where a DLI was correctly diagnosed in 1 level, but an additional level obtained intraoperatively was not considered. In 26 patients, the localization of the T2 hyperintense signal correlated with level of DLI confirmed intraoperatively. In 1 case, DLI was detected in the adjacent level of the contusion seen on MRI.

Krappinger et al. obtained a relevant increase in sensitivity from 60% to 88% when images were interpreted by an experienced MRI radiologist compared to the radiologist on call. In our recently published study, the sensitivity of preoperative MRI imaging to identify DLI of the cervical spine was 77.4%, when correlating with intraoperative findings (Janssen et al., 2021). When considering prevertebral hematoma as detected by preoperative imaging (on the level of confirmed DLI according to intraoperative situs inspection) as an indirect sign of DLI, the sensitivity increased to 83.9%. Furthermore, we observed that the presence of severe degenerative changes, lead to restrictions for diagnostic yield of preoperative imaging. Considering MRI is less sensitive in the presence of underlying spondylosis, DLI may be underdiagnosed, especially in elderly patients with CCS who have underlying degenerative cervical stenosis.

This was confirmed in our study, in which DLI was not visible in preoperative MRI in 2 cases. In 5 patients, DLI was correctly diagnosed but missed in 1 additional level each.

In contrast to previous studies on this topic, which used images from 1.5-T systems, all images in the present study were obtained from 3-T systems. Given the high variability of values, which ranged from approximately 48%–100% for ALL and from 50% to 93% for PLL injury in studies at 1.5-T MRI, and given that Henninger et al. reported similar results to ours, no conclusion on possible superiority of the 3-T MRI can be drawn from the available studies (Henninger et al., 2020; Malham et al., 2009a; Goradia et al., 2007a; Zhuge et al., 2015). The correct selection of sequences and the assessment by experienced radiologists seems to be of greater importance in the context of our question (Krappinger et al., 2019).

When interpreting the results of this study, some limitations have to be acknowledged. First, the retrospective character of the study carries the risk of inaccuracies and incompleteness in the documentation of perioperative observations. Furthermore, although all MRI data considered was uniquely taken from 3-T systems, differences in scanning protocols cannot be ruled out. Our study does not provide data concerning comparison of outcome depending on surgical timing. However, these data are from a prospective database with homogeneous pre-, intra-, and

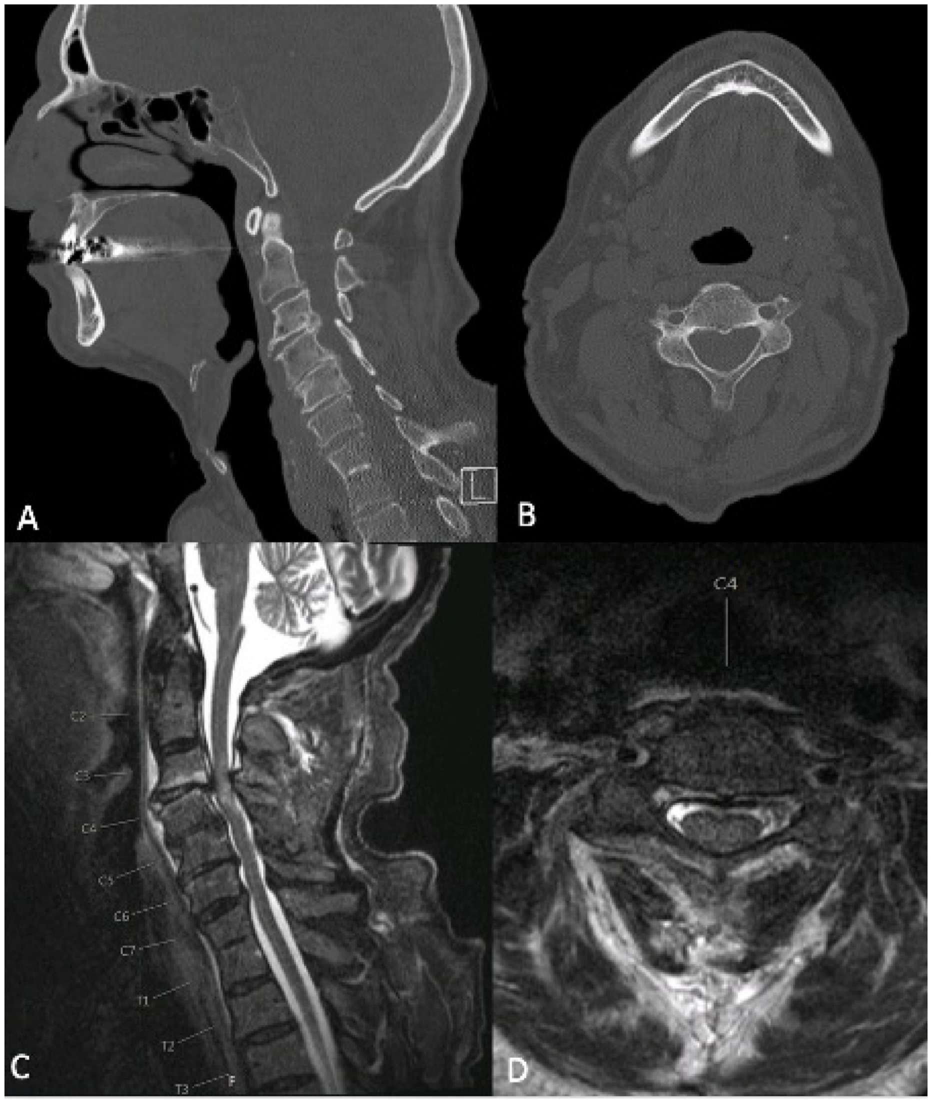

Fig. 2. Example for necessity of MRI in traumatic spinal cord injury: 74-year-old male patient with ventrolisthesis C3/4 on CT scan (A,B) but without notion of hematoma or fractures. A contusion on C3/4 could be detected as well as a DLI in MR imaging (C,D).

postoperative management. The incidences given therefore seem reliable.

Our findings support the importance of high-resolution MRI, including T2-weighted and STIR sequences for detecting DLI in all patients with CCS even when no bony lesion is seen in cervical CT scan. Furthermore, it is our recommendation and practice to perform additional MRI for any bony lesion detected on CT to detect possible additional occult disco-ligamentous lesions, as it was shown in our recently published study that fractures can be indirect signs of disco-ligamentous injuries (Janssen et al., 2021). Considering the results of Krappinger et al., evaluation of MRI should be performed by a specialized radiologist. Furthermore, the high incidence of DLI in our cohort as well as the limited sensitivity of MRI for diagnosis support the recommendation of surgical intervention in patients with traumatic CCS to avoid secondary damage due to persisting instability.

5. Conclusions

The incidence of DLI in patients with traumatic CCS based on preexisting spinal stenosis was 60.78%, which is higher than previously reported. Preoperative high-resolution MRI including T2-weighted and STIR sequences are mandatory in diagnosing patients with CCS, although the sensitivity for detecting DLI is limited in patients with preexisting degenerative cervical spondylosis (79%), which indicates the risk of missing a traumatic disco-ligamentous injury in these patients. This should be considered in the decision making process and may underpin the importance of surgical treatment in patients with traumatic CCS based on preexisting spinal stenosis.

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Declaration of competing interest

BM reports a financial relationship to Ulrich Medical, Medtronic, Depuy Synthes, Brainlab, Spineart, Relievant, Medacta, Icotec, AO Spine, Eurospine, and IGASS where he acts as a consultant. He has received personal fees and research grants outside the submitted work.

JG has received honoraria for lectures, consultation from BrainLab, Zeiss, and Medtronic. The following for-profit companies have supported clinical trials and contracted research conducted by JG with payments made to his institution: Zeiss.

SK is consultant for Ulrich medical (Ulm, Germany) and Brainlab AG

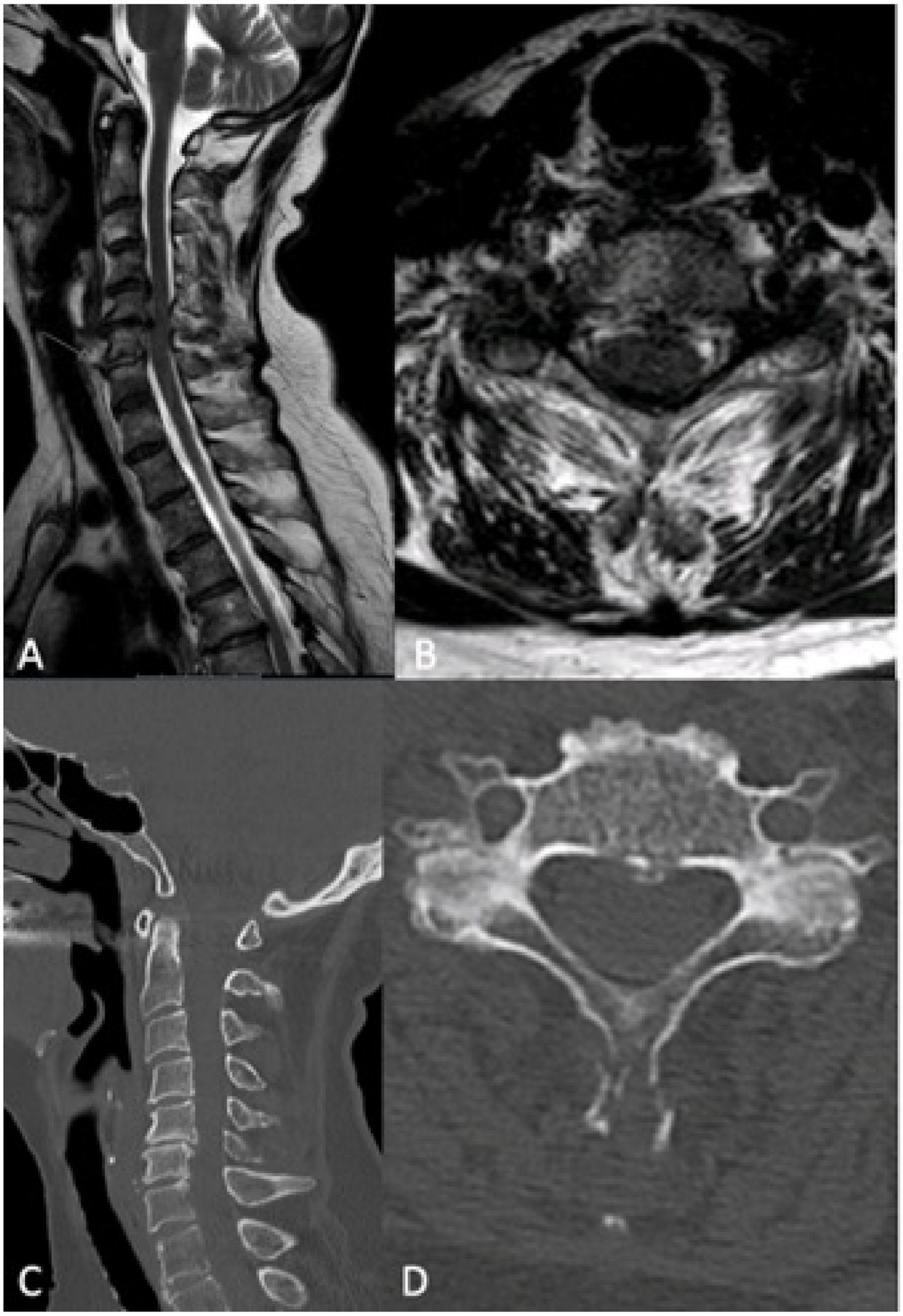

Fig. 3. Example of an additional segmental instability observed at an adjacent segment in a 71-year-old female patient: T2 signal abnormality in the C6/7 disc space was considered highly suspicious for DLI at this level. Additional findings were a contusion on C5/6 and a prevertebral hematoma from C6–Th2 in MRI (A,B). On CT scan, fracture of the spinous processes of C6 with a dehiscence defect of approximately 6 mm was detected (C,D). Intraoperatively DLI was confirmed on C6/7 but also additionally in the level C5/6 which was not seen on preoperative MRI.

Table 2
Distribution of suspected DLI in MRI, confirmed DLI during surgery and level of contusion.

	Suspected DLI in MR imaging n = 33	Detected DLI intraoperatively n = 29	Contusion n = 44
C 2/3	3.0% (1/33)	0% (0/29)	2.3% (1/44)
C 3/4	39.4% (13/33)	31.0% (9/29)	34.1% (15/44)
C 4/5	45.5% (15/33)	51.7% (15/29)	36.4% (16/44)
C 5/6	48.5% (16/33)	51.7% (15/29)	43.2% (19/44)
C 6/7	18.2% (6/33)	20.7% (6/29)	11.4% (5/44)

(Munich, Germany) and received honoraria from Nexstim Plc (Helsinki, Finland), Spineart Deutschland GmbH (Frankfurt, Germany), Medtronic (Meerbusch, Germany), and Carl Zeiss Meditec (Oberkochen, Germany).

All other authors certify that they have no affiliations or involvement in any organization or entity with any financial interest (eg, honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements) or nonfinancial interest (eg, personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

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