Eur Spine J (2001) 10 : 154–163
DOI 10.1007/s005860000238

ORIGINAL ARTICLE

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Traumatic intervertebral disc lesion – magnetic resonance imaging as a criterion for or against intervertebral fusion

Received: 30 November 1999
Revised: 12 October 2000
Accepted: 31 October 2000
Published online: 24 January 2001

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Abstract Lesions of the intervertebral disc accompanying vertebral fractures are the subject of controversy and discussion regarding the extent and manner of surgical intervention. The question of when to perform disc resection and intervertebral fusion, in particular, has not been answered satisfactorily. In order to evaluate short- and medium-term lesions of the discoligamentous complex associated with thoracolumbar burst fractures, magnetic resonance images made after stabilisation and again after implant removal were compared. Between 1997 and 1998, 20 patients who had suffered thoracolumbar burst fractures (AO classification A3 and B1 [26]) underwent posterior reduction and stabilisation using a Universal Spine System (USS, Synthes, Switzerland) titanium internal fixator. The implant was removed after an average of 10 months. Magnetic resonance imaging (MRI) scans were performed 1 week after both operations, allowing the changes in a total of 40 intervertebral discs adjacent to the fractured vertebral body to be investigated. The analysis was based on signal intensity of the intervertebral disc in T_2-weighted scans and on morphological criteria. A total of 81% of the discs with initially normal T_2-weighted signal showed the same signal after implant removal; 5 discs with initially increased signal intensity in T_2-weighted scans normalised, 5 showed a decrease in intensity and 3 suffered a partial loss of signal. Among the 9 discs with initially decreased T_2-weighted signal, only one had normalised by the time the implant was removed. A total of 86% of the 14 morphologically intact discs retained their structural integrity. Of the 25 discs with minor defects, only one could be considered as intact after implant removal, 15 remained the same and 9 deteriorated in structure. No disruption of the fibrous ring or of the posterior longitudinal ligament was observed, nor was there any prolapse of intervertebral discs. When the intervertebral disk is intact and has normal morphology and a normal T_2-weighted MRI signal, resection or fusion of the fracture adjacent discs appears unjustified. In our opinion, the results do not support the possibility of predicting degradation in those discs that showed an altered T_2-weighted signal after the first operation.

Keywords Spinal fracture · Magnetic resonance imaging · Degeneration · Disc-preserving procedure

Introduction

Recommendations for the therapy of unstable thoracolumbar burst fractures range from strictly conservative treatment [2] to an extensive dorsoventral procedure with removal of the intervertebral discs and autologous bone grafting [17, 34, 35, 39].

The main argument for intervertebral fusion is the loss of correction after a non-fusing operation, caused by degeneration of the discs cranial and caudal to the fractured vertebral body [3, 9, 18,41]. As a consequence, segmental instability and progressive angular kyphosis can occur, which may cause static imbalances or even neurological symptoms by compromising tension of the spinal cord above the gibbus.

Recent investigations, however, show that a good functional result can be achieved in the injured segment by dorsal reduction and temporary stabilisation using internal fixation [6, 36]. In addition, comparison of dorsal versus dorsoventral techniques showed loss of correction with or without intervertebral bone grafts [42, 44].

There is consensus that a way of evaluating the risk of structural damage to be expected in the course of a vertebral fracture needs to be found. X-rays fail to give information about the intervertebral disc. Discography allows the intervertebral pressure to be measured and shows tears in the fibrous ring, but this is an expensive and invasive examination [31, 32]. Using magnetic resonance imaging (MRI), not only can structural changes in an intervertebral disc be assessed more accurately than by conventional X-ray, but biological changes can also be made visible [4, 12, 40]. In addition, MRI allows the integrity of the anterior and posterior longitudinal ligament to be evaluated and shows the bony reaction in the form of oedema and scarring processes. By using titanium implants, MRI can be performed with the fixator in situ without unacceptable artefacts [1]. It is therefore possible to monitor the injured segment after dorsal reduction and stabilisation to the moment of implant removal and thereafter [45].

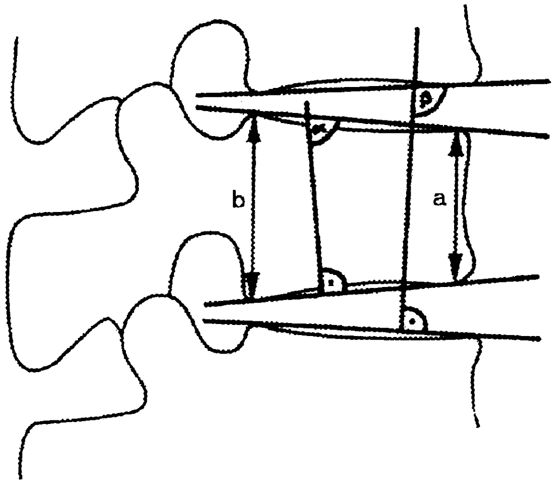

Fig. 1 Parameters in conventional X-ray and computed tomography (CT) [6]: α, vertebral body angle (VBA); β, bisegmental wedge angle (BWA); *a/b*, sagittal index (SI), measured by taking the quotient of the anterior and posterior vertebral body height

Materials and methods

From January 1997 to March 1998, thoracolumbar burst fractures of AO classification type A3, B1.2 or B2 in combination with fracture of the vertebral body, but without neurological impairment, were treated in 20 patients using the Universal Spine System (USS, Synthes, Switzerland) by performing dorsal reduction and temporary spondylodesis without anterior fusion. The implants were removed an average of 10 months after implantation. The ratio between male and female patients was 14:6. The injury was caused by a fall in 11 patients, a motorbike accident in 2, a car accident in 4 and a sport accident in 3. The average age of the patients was 42 years (range, 12–66 years). Only fractures of the thoracolumbar spine from T12 to L2 without neurological impairment were included in the study. In the 20 patients, there were 2 T12, 13 L1 and 5 L2 fractures. Only AO fracture classification types A3, B1.2 and worse in which the posterior wall was pushed into the spinal canal were included. Because of the minimally invasive approach that was used in most cases, ligamentous disruption was not able to be clinically verified in these cases.

Preoperative diagnostic procedures included conventional X-ray and computed tomography (CT). Preoperative MRI was not obtained in all of the cases, because surgery was performed immediately after a CT scan in patients with multiple traumas. Impairment of the spinal canal, sagittal index (SI), kyphosis angle (vertebral body angle, VBA) and bisegmental wedge angle (BWA) were measured before surgery, after implantation and after implant removal (Fig. 1). The neurological status was intact in all of the patients before and after spinal surgery. MRI was performed in all the patients 1 week after internal fixation and implant removal. Either an Elscint 0.5-T imager or a Gyroscan T5 was used to create standardised images in turbo spin echo (TSE) sequences with a T_1-weighted (TR 600, TE 20) and T_2-weighted signal (TR 3000, TE 150). The patient's position relative to the coil was the same in all of the examinations, giving standard MRI sequences of the lower thoracic and lumbar spine. A radiologist and an orthopaedic surgeon together assessed the images. Morphological changes were divided into three categories, following a modified von Gumppenberg classification [13]. Category 1 meant that no difference between the injured disc and a comparable non-injured disc could be seen. Category 2 discs had assumed a more ellipsoid form or had small bulges into the vertebral endplate. Category 3 discs were infracted into the vertebral body or herniated into the endplate.

MRI signal intensity was analysed according to T_2-weighted signal variation. With regard to comparative studies, T_2-weighted signal intensity was regarded as reflecting the water content. Although quantitative statements on the biochemical composition do not seem to be justified, conclusions can be drawn on the content of water-binding proteoglycans and collagens and thus the degree of degeneration estimated [4, 24, 40]. The discs adjacent to the fracture were compared to non-injured discs in segments below, mostly L3/4. A four-stage classification was used, dividing the signal into “increased”, “normal” and “decreased” T_2-weighted signal intensity and vacuum phenomenon with “partial loss” of the nucleus signal (Fig. 2). The data obtained should be considered as the result of a subjective assessment, as it was not possible to measure the signal intensity. The assessment should therefore be regarded with caution. A possible solution would have been to compare the disc signals to a test tube placed in the coil. However, in view of

Fig. 2 A, B After stabilisation of an L1 fracture. **A** The T12/L1 disc has decreased signal intensity, and the morphology was classified as category 2. The L1/2 disc has normal signal intensity and category 1 morphology. **B** The cranial disc shows a partial loss of T_2-weighted signal and category 3 morphology, while the caudal disc has normal signal intensity despite category 3 damage. *A*, anterior; *B*, posterior

the different age of the patients and the naturally differing disc signal intensity, the results obtained would not have taken into account the age-related changes.

Results

X-ray data

In all cases, the displaced bone fragment compromised the spinal canal by an average of 40% in anterior-posterior (AP) diameter (18–66%). Only by distraction using the effect of indirect reduction was it able to be reduced to 11% (0–28%). The VBA increased from a kyphosis of –15.5° after trauma to –5.8° after reduction and was –6.4° after implant removal. By analogy, the SI increased from 0.64 to 0.88 without any significant loss of correction (0.87). The BWA was –3.4° before and +4.9° after implant installation, i.e. correction of 8.3°, but reverted to –1.8° after removal of the internal fixator (Table 1).

MRI signal and disc morphology after fracture reduction and implant removal

After trauma. After fracture reduction, a normal pulpy nucleus signal was found in 16 discs (40%). As an expression of trauma and distraction, 15 discs (37.5%) had an increase of signal intensity in T_2-weighted scans. In 9 discs (22.5%), signal intensity was already decreased. There were no discs with a loss of T_2-weighted signal.

According to morphological criteria, 14 discs were assessed as normal (category 1) after reduction, 25 had slight changes in structure (category 2) and only one disc was classified as severely damaged (category 3) (Table 2).

Implant removal. After implant removal, 19 discs (47.5%) showed a normal T_2-weighted signal, and 3 discs still had an increase in T_2-weighted signal. A decreased T_2-weighted signal was found in 15 discs (37.5%). A vacuum phenomenon was seen in 3 discs as an expression of severe degeneration.

The morphology was normal in 13 of the examined discs (32.5%), 17 discs (42.5%) were classified as having

Table 1 Patients and conventional radiological data (see also Fig. 1)

Vertebra	AO	Before surgery			After stabilisation			Implant removal			Overall correction	LoC-BWA	LoC-VBA
		BWA	VBA	SI	BWA	VBA	SI	BWA	VBA	SI			
L2	A 3.1.1	–9	–14	0.86	6	–2	0.93	2	–6	0.90	15	–4	–4
L1	A 3.2.1	–8	–22	0.59	8	–5	0.84	0	–4	0.95	16	–8	1
L1	A 3.2.1	–15	–17	0.57	–4	–8	0.83	–4	–6	0.83	11	0	2
L1	A 3.2.1	–6	–14	0.71	4	–6	0.89	–6	–7	0.89	10	–10	–1
L1	A 3.2.1	2	–15	0.70	10	–5	0.91	–3	–4	0.94	8	–13	1
L2	A 3.2.2	0	–16	0.58	6	–4	0.95	–2	–7	0.90	6	–8	–3
T12	A 3.2.1	2	–18	0.61	12	–10	0.79	–2	–17	0.59	10	–14	–7
L1	A 3.3.2	–5	–14	0.72	2	–6	0.87	–4	–7	0.84	7	–6	–1
L1	A 3.1.1	–12	–15	0.68	0	–5	0.90	0	–3	0.93	12	0	2
L1	A 3.1.1	–6	–12	0.67	0	–9	0.79	–16	–8	0.83	6	–16	1
L1	A 3.1.1	0	–22	0.55	10	–6	0.86	10	–7	0.88	10	0	–1
L1	A 3.1.1	4	–6	0.88	6	–8	0.78	0	–6	0.90	2	–6	2
L1	B 1.2.1/A 3.3.2	–14	–23	0.44	–4	–7	0.86	–10	–8	0.82	10	–6	–1
L2	A 3.2.2	10	–8	0.82	12	0	1.00	7	–1	1.00	2	–5	–1
L1	A 3.2.2	0	–10	0.71	0	–4	0.90	0	–6	0.84	0	0	–2
L2	A 3.2.1	–1	–21	0.42	4	–4	0.88	0	–4	0.89	5	–4	0
L2	B 1.2.1/A 3.2.1	0	–12	0.78	10	3	1.05	0	0	1.00	10	–10	–3
L1	A 3.1.1	2	–16	0.62	7	–10	0.88	–2	–6	0.90	5	–9	4
T12	A 3.1.1	–8	–20	0.52	4	–12	0.74	–9	–13	0.71	12	–13	–1
L1	A 3.1.1	–4	–14	0.48	5	–7	0.88	4	–8	0.88	9	–1	–1
	Mean±SD	–3.4±6.26	–15±4.53	0.64±0.13	4.9±4.68	–5.8±3.42	0.88±0.07	–1.75±5.63	–6.4±3.64	0.87±0.09	8.3±4.10	–6.65±4.90	–0.65

AO, classification of the fracture type according to Magerl et al. [26]; BWA, bisegmental wedge angle; VBA, vertebral body angle; SI, sagittal index; LoC-BWA, loss of correction of BWA; LoC-VBA, loss of correction of VBA; SD, standard deviation.

Table 2 Course of the magnetic resonance imaging (MRI) signal and morphological features from stabilisation until implant removal (for signal and morphology classification criteria, see Fig. 2)

Patient	Cranial disc				Caudal disc			
	Implantation		Removal		Implantation		Removal	
	Signal	Morphology	Signal	Morphology	Signal	Morphology	Signal	Morphology
1	Increased	2	Decreased	2	Normal	1	Normal	1
2	Decreased	2	Normal	2	Decreased	2	Decreased	2
3	Increased	2	Normal	2	Normal	2	Decreased	2
4	Increased	2	Normal	2	Normal	1	Normal	1
5	Decreased	2	Decreased	2	Decreased	2	Decreased	3
6	Increased	2	Increased	3	Increased	1	Decreased	2
7	Increased	2	Loss of signal	3	Increased	2	Degenerated	2
8	Decreased	2	Decreased	3	Decreased	2	Decreased	2
9	Normal	1	Normal	1	Normal	1	Normal	1
10	Increased	2	Normal	1	Normal	1	Normal	1
11	Normal	1	Normal	1	Normal	1	Normal	1
12	Increased	2	Normal	2	Decreased	2	Decreased	2
13	Increased	2	Loss of signal	3	Normal	2	Normal	3
14	Increased	3	Normal	3	Normal	2	Normal	2
15	Normal	2	Decreased	3	Normal	1	Normal	1
16	Decreased	2	Increased	3	Decreased	1	Decreased	2
17	Increased	2	Increased	2	Normal	1	Normal	1
18	Increased	2	Decreased	3	Normal	1	Decreased	1
19	Increased	2	Decreased	2	Normal	1	Normal	1
20	Increased	2	Decreased	2	Normal	1	Normal	1

Table 3 Characteristics of the MRI signal from stabilisation until implant removal (81% of the discs with normal signal keep this at least for the time of temporary stabilisation)

MRI signal after trauma	MRI signal after implant removal (% of discs)			
	Increased	Normal	Decreased	Degenerated
Increased (*n*=15)	13.33	33.33	33.33	20
Normal (*n*=16)	0	81	19	0
Decreased (*n*=9)	11	11	78	0

Table 4 Disc morphology after primary stabilisation compared to that after implant removal (86% of initially intact discs stay intact)

Disc morphology after trauma	Disc morphology after implant removal (% of discs)		
	Category 1	Category 2	Category 3
Category 1 (*n*=14)	86	14	0
Category 2 (*n*=25)	4	60	36
Category 3 (*n*=1)	0	0	100

minor damage (category 2), and 10 discs (25%) as severely damaged (category 3).

Course of signal intensity

Of the 15 discs with increased signal after trauma, one third normalised and one third showed a decrease in T_2-weighted signal intensity. A total of 21% had partial loss of signal.

In 13 of 16 discs (82%) with normal signal after trauma, T_2-weighted signal intensity remained the same until implant removal and decreased in 3 patients (18%). In one case, an increase in the T_2-weighted signal was found between implantation and removal.

In the cases in which the T_2-weighted signal was found to be decreased after trauma (9 discs), recovery of T_2-weighted signal intensity was observed in one case and one disc even showed an increased signal on T_2-weighted scans. However, in 7 of 9 discs, signal intensity was found to be permanently reduced (Table 3).

Course of morphological features

Of the 14 morphologically intact discs, 12 remained intact (86%) and the other 2 were partially defective (category 2).

In the 25 discs that were initially altered (category 2), the morphology remained the same in 60% and degraded to category 3 in 37% (9 discs). Normalisation was seen in 1 disc. The disc classified as being category 3 after trauma showed no recovery (Table 4).

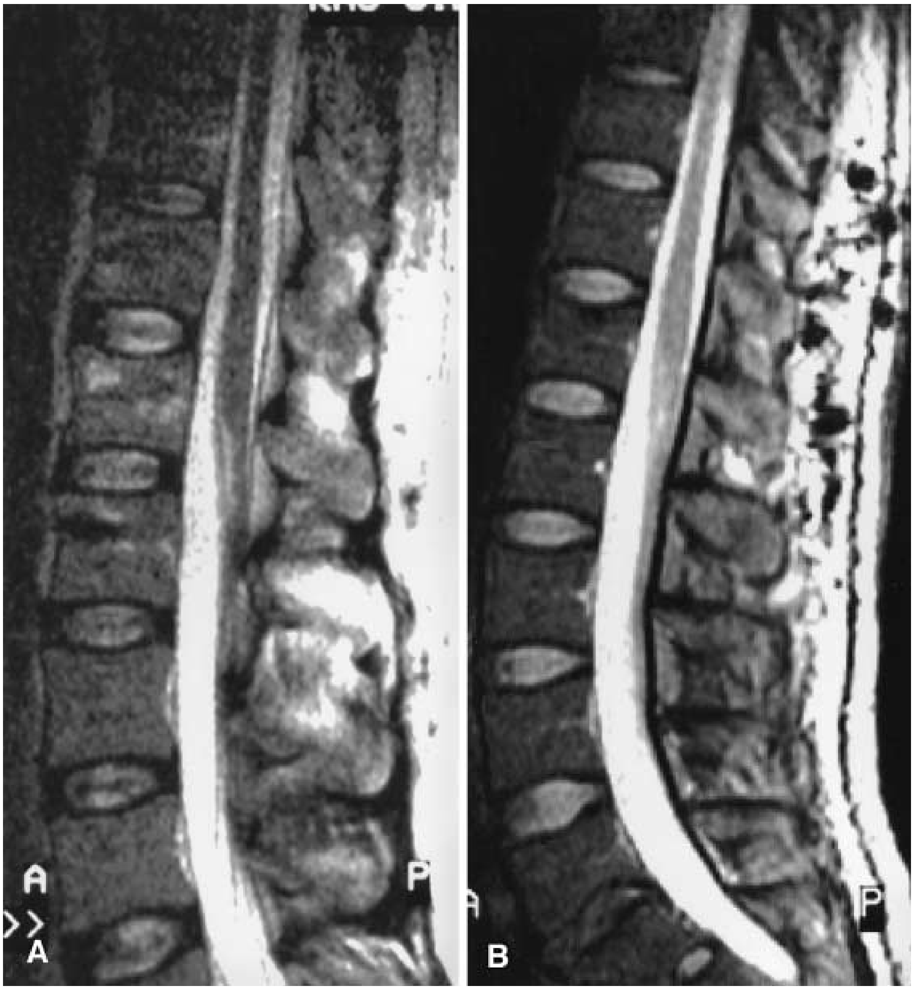

Fig. 3 **A** Magnetic resonance imaging (MRI) in patient no. 11 (see Table 2) after stabilisation of an L1 fracture. **B** Same patient as in Fig. 3a. MRI after implant removal shows complete recovery. *A*, anterior; *P*, posterior

Disc morphology and signal as prognostic factors for short-term degeneration

A total of 12 discs (3 cranial and 9 caudal) showed physiological features of signal and morphology after stabilisation. In 11 of these (27.5% of all the discs examined), an intact disc was found after implant removal, while one showed a loss in T_2-weighted signal but an intact appearance.

Of the 4 discs classified as having a normal signal and morphological category 2, signal intensity decreased in 2. In the discs in which an increased signal intensity was found after stabilisation (n=13), the degeneration to be expected could not be predicted, with 2 discs showing an increased signal, 4 normal, 4 decreased and 3 a totally degenerated signal (Figs. 3, 4).

If discs were classified as morphological category 2 after stabilisation, no major changes in appearance were seen, and there was infraction into the endplate or loss of substance in any of them, regardless of the signal found (Fig. 5).

Discussion

Intervertebral discs are shown to resist pressure injury better than the vertebral body [5, 28, 33]. Under fast loading conditions, as occur in fractures, the partially fluid disc behaves like a solid body [16]. Thus injury to the disc does not seem to be inevitable in vertebral burst fractures. In disc-preserving procedures, operative or non-operative, a continuous loss of anterior height producing post-traumatic kyphosis has been observed. Progressive disc degeneration was claimed to be responsible for this phenomenon [9]. The loss of height of the intervertebral disc was shown to produce a significant loss of stability in the segment concerned by relaxing the oblique ring fibres [22,25], an effect that accelerates degeneration again. Kluger et al. [18] predicted the amount of kyphosis by measuring the intervertebral disc angles and dividing them by the Cobb angle. Marked kyphosis can lead to secondary problems, i.e. sagittal imbalance or anterior spinal artery syndrome. Based on long-term observations, it was

Fig. 4 Intact discs after implant removal in patient no. 10 (see Table 2), but kyphosis due to herniation of the disc into the vertebral body. *A*, anterior; *P*, posterior

presumed that back pain appears years after the injury in patients with kyphosis angles of 15° or more [3,41].

However, recent MRI studies demonstrated that the majority of the discs adjacent to the fracture remain morphologically and biologically intact [36] and that loss of correction seems to be the result of the disc creeping into the central depression of the vertebral endplate [29]. Nevertheless, MRI did not always detect acute herniation or tears in the fibrous ring [37]. In an animal model, it was shown that T_2-weighted spin echo can fail to detect disc degeneration until 12 months after trauma [30]. Comparable studies have not yet been conducted in human patients.

In the case of fragments pressed into the canal, ligamentotaxis has proved to achieve a good reduction of impairment of the spinal canal. Biomechanical studies have shown that fragments adherent to the disc are repositioned, and canal clearance to less than 35% impairment of the canal can be achieved by applying indirect tension on the posterior longitudinal ligament (PLL) [10, 14, 38]. By performing pediculation and distraction according to the principle presented by Dick and Kluger, a disc-preserving procedure can be used that can even be performed using minimally invasive surgery [44]. Blood loss can be reduced by 30% compared with the open paraspinal approach. Residual mobility can help to regenerate the disc, as motion is essential for nutrition [15]. Experimental findings indicate the dynamic nature of posterior fusion and underline the importance of distraction. The intradisc pressure has been shown to be the same in dorsally stabilised and non-stabilised segments [43], and loss of correction was found to be similar even when pedicle screws were broken [34].

The effect of anterior bone grafting is controversial. Segmental stability was found to be reduced in anterior iliac crest grafting compared with dorsal stabilisation alone [27]. Only anterior stabilisation was thought to guarantee stable correction [7,17], but at the price of a high rate of procedure-related morbidity, the problem of remaining implants and possible instability of the neighbouring segments [35]. Even in anterior stabilisation, loss of correction of 22.9% has been reported [20].

There are no studies about the incidence of complications caused by post-traumatic kyphosis or recommendations about the kyphosis angle that can be tolerated.

Kyphosis angles below 20° do not seem to influence the clinical outcome [8, 11]. Nevertheless, in the case of revision surgery or even kyphosis correction, the risk is evident [21].

In the study mentioned above, it was possible to achieve sufficient canal clearance by means of a disc-preserving procedure. The loss of correction does not significantly differ from earlier studies with or without transpedicular or posterolateral interbody fusion (PLIF) [19, 23]. Results concerning morphological or functional injury of the disc resemble those obtained in recent studies [36], which found 30% normal MRI signals and 15% normal morphology after segment-preserving dorsal reduction. In the above-mentioned study, the morphological integrity of the disc was able to be demonstrated in 30% of the discs after initial stabilisation and in 28% after implant removal, and we were able to monitor the disc signal from the time of injury up until the time of implant removal. An intact segment was found after release of the spondylodesis in 92% of the discs with intact signal and morphological features after trauma. Although the observation period was short (10 months on average), the results show that there are MRI criteria that may be helpful in assessing the degree of injury to the intervertebral disc and the further degeneration to be expected. It appears to be difficult to give a prognosis if there is primary alteration of the disc signal or morphology, but disc morphology did not seem to change during the observed interval. Since no histological samples of the disc were taken, the biochemical

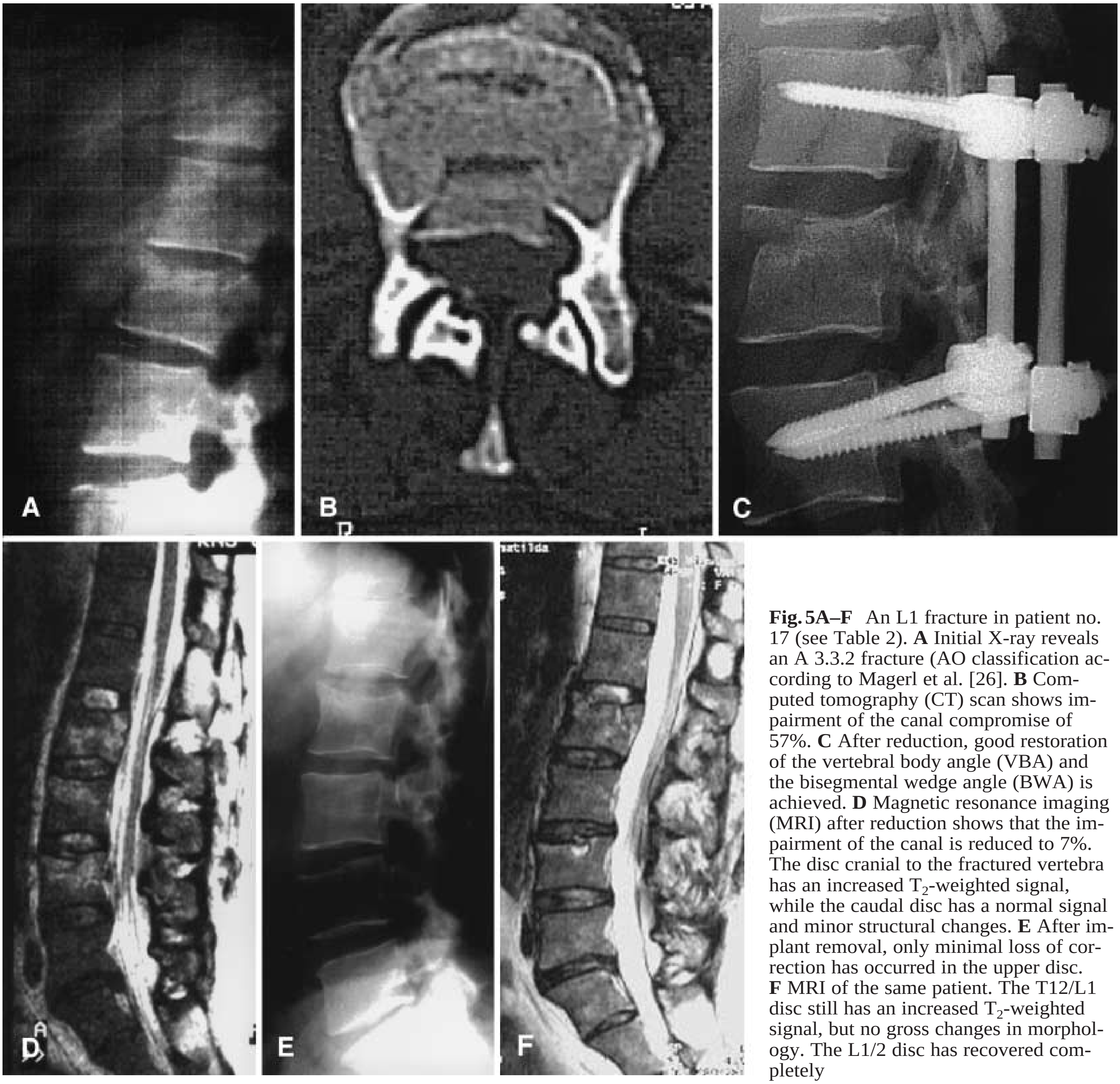

Fig. 5A–F An L1 fracture in patient no. 17 (see Table 2). **A** Initial X-ray reveals an A 3.3.2 fracture (AO classification according to Magerl et al. [26]. **B** Computed tomography (CT) scan shows impairment of the canal compromise of 57%. **C** After reduction, good restoration of the vertebral body angle (VBA) and the bisegmental wedge angle (BWA) is achieved. **D** Magnetic resonance imaging (MRI) after reduction shows that the impairment of the canal is reduced to 7%. The disc cranial to the fractured vertebra has an increased T_2-weighted signal, while the caudal disc has a normal signal and minor structural changes. **E** After implant removal, only minimal loss of correction has occurred in the upper disc. **F** MRI of the same patient. The T12/L1 disc still has an increased T_2-weighted signal, but no gross changes in morphology. The L1/2 disc has recovered completely

changes can only be presumed. In our opinion, the initial increase of signal intensity in T_2-weighted scans is due to increased water content as a result of injury (oedema) and to the segmental distraction during reduction, a phenomenon that may be similar to the diurnal change of disc height under compression and decompression. Those discs demonstrating an increased signal after trauma show all kinds of signal and morphology after implant removal, making prognosis impossible in these cases. In our view, the decrease in signal intensity must be caused by degenerative processes, but even here recovery of an initially decreased signal intensity was seen on T_2-weighted scans in 2 patients. Age does not appear to correlate with signal, morphology or outcome in conventional X-rays. This is perhaps due to the comparison of injured and non-injured discs in the same individual. Many elderly patients showed disc degeneration in non-injured segments, mostly L4/L5 and L5/S1, which may influence the clinical outcome because of a reduced capacity for compensation.

Conclusions

The following conclusions may be drawn:

1. In the case of thoracolumbar burst fractures of types A3 and B1, intervertebral disc resection and fusion, either anterior or posterior, is not recommended if the disc is intact after trauma and initial stabilisation.
2. In the case of intact morphology, the MRI signal can vary but does not influence the morphological course. Fusion is not recommended in these cases either.
3. Slightly altered disc signal and morphology may influence the process of degeneration. Control radiographs at yearly intervals are recommended to document the progress of kyphosis and to allow anterior fusion to be performed in time, if necessary.
4. Obvious morphological alterations, especially in combination with an increase or partial loss of the T_2-weighted signal, are relative indications for inter-body fusion.
5. MRI after initial stabilisation helps to decide whether or not to fuse thoracolumbar burst fractures, but does not obviate the need for assessment by a spinal surgeon.

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