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Correlation of MR images of disc injuries with anatomic sections in experimental thoracolumbar spine fractures

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Abstract This cadaver study evaluated the value of MR images for detection of acute intervertebral disc damage associated with fractures of the thoracolumbar spine. Damage to the intervertebral disc may be a major contributor to chronic instability in non-operative treatment or failure of fixation and recurrence of deformity in posterior fixation methods. MR imaging can help us to understand the injury patterns and their prognostic significance. However, before we can justify the use of MRI in clinical cases, determination of MRI’s ability to detect acute injury to the disc is necessary. Ten fresh cadaver specimens were used for this study. After obtaining radiograms and MR images, injuries were created with a weight-dropping apparatus using a variety of weights and compression angles. Post-injury radiograms and MR images were taken and the specimens were frozen at –20 °C. Slides of these specimens obtained with cryosection techniques were compared with MR images for evaluation of the damage to different parts of the discs. A total of 20 fractures were observed on cryosections. In 12 of the discs adjacent to fractured vertebral bodies, macroscopic damage was seen on the sections. These were all detected on the corresponding MR images. The study showed that MRI is able to detect acute, macroscopic injury to the intervertebral disc. It is therefore justified to use MR for the study of acute disc damage associated with thoracolumbar fractures.

Key words Spine fractures · Trauma · MRI · Intervertebral disc · Cadaver study

Introduction

The role of intervertebral disc injury in the acute stability and long-term prognosis of thoracolumbar spine fractures is still poorly understood. The bony part in a vertebral fracture usually heals completely and returns to normal strength, but the healing of the relatively avascular disc is unpredictable and may depend on the pattern of injury sustained [13, 18]. This may partly explain the variations in the results of conservative treatment and the differences in failure rates of posterior fixation reported in the literature [3–7, 15–17, 22–25]. Disc space narrowing has commonly been observed and has been has been associated with recurrent kyphosis and as well as complications after posterior fixation [1, 2, 4, 8, 21, 22]. A biomechanical study showed that about 60% of the acute hypermobility after a compression-type fracture is situated in the surrounding discs [13]. Thus the failing disc may be a major contributor to chronic instability [13, 18]. The patterns of injury and healing of the discs are largely unknown. The functional integrity of the disc, however, does seem to influence the type of fractures in mechanical experiments and clinical observations [10, 20]. Especially in common compression-type fractures, injury and healing patterns can be crucial in determining the outcome of non-operative treatment or posterior short-segment fixation. The AO classification system of thoracolumbar spine fractures emphasises the prognostic influence of soft tissue injury associated with fractures and separate discoligamentous injuries from osseous lesions [14]. This classification system makes also some implicit assumptions about the integrity of the disc, based on indirect evidence from radiograms and CT scans. Mechanical studies have shown that the anatomy of the fracture itself is the most important factor in the failure of posterior constructs [16]. Based on these observations, a load-sharing classification has been devised, with a good prognostic value [16]. Inclusion of disc injury and healing patterns in this scheme may increase the predictive power of this classification and help rationalise treatment regiments.

Conventional imaging modalities, however, are not capable of identifying disc injury patterns. Although MRI is a potentially useful tool to study the effects of different disc injury and healing patterns in clinical cases, it is not known whether it is possible to detect disc injuries associated with fractures. Frederickson et al. used MR images for the study of distractibility of posterior fragment in a burst fracture model [9]. They were able to image the posterior annulus sufficiently to study its relation with the reduction of the fragment with distraction. However, they did not specifically study the associated injuries of the whole disc. Therefore, we designed this study to determine whether MRI is capable of detecting macroscopic injury to the disc in a cadaveric fracture model.

Materials and methods

Thoracolumbar spine specimens obtained from ten fresh human cadavers without any macroscopic evidence of infectious or neoplasmic disease were used. The average age of the specimens was 64 years (47–79 years). All muscles were removed with care, so as not to damage ligaments or facet joints. The thoracolumbar junctions with five to seven vertebrae, depending on the length of the spine, were removed. These specimens were fixed between two polyethylene cylinders filled with polyurethane, leaving one or two motion segments free. Anteroposterior and lateral radiograms and sagittal MR images of the specimens were obtained. The vertebrae and the discs were sequentially numbered from cranial to caudal. For MR imaging we used a 1.5-T Philips Gyroscan ACS-NT. T2-weighted spin echo (TR: 2200, TE: 22) and T2-weighted turbo spin echo (TR: 1481, TE 106) sequences were used. The T2-weighted spin echo sequences were the same as used by Frederickson et al. [9]; T2-weighted spin echo is one of the sequences used at our hospital in acute trauma cases. Fractures were created with a specially designed weight-dropping device with features allowing different weights and varying flexion angles. No attempt was made to standardise in any way the type of fractures, as we tried to create as many types of injury to the vertebral body bodies and the discs as possible. Therefore, we used different weights and flexion angles in each of the specimens. After the injury, radiograms and MR images of the specimens were obtained with the same sequences within the same day. Then the specimens were frozen at –20 °C in plastic bags to prevent drying. Sagittal sections of 5 mm were cut with a high-speed saw and photographed. To investigate whether this technique was adequate to detect all injuries, we used a more detailed analysis in two of the specimens. In these two specimens, multiplanar 3D reconstructions were created with data obtained from volumetric MR acquisitions. For these two specimens a micro-cryoplaning technique was used to obtain sagittal sections of 30 μm [12]. Each section was photographed and digitally recorded. Of these two specimens, slides at intervals of 5 mm were collected on adhesive tape and stained with haematoxylin and eosin (H&E) to observe possible changes, undetectable without staining.

Radiograms and MR images of the specimens before and after the injury were evaluated by the radiologist. Pre-existent disc pathologies, fractures of the vertebral bodies, and changes in the discs between the first and second MR images were described. Changes in the disc space were described as:

1. Ruptures through the anterior, middle or posterior one-third
2. Herniation of the nucleus pulposus in the endplates
3. Changes in signal intensity in the disc space

The first author, without access to the radiograms and MR images evaluated the anatomical sections. The central one-third of the sagittal sections were used to identify:

1. Fractures of bony parts
2. Long-standing degenerative changes in the discs
3. Schmorl's nodes
4. Ruptures through anterior and posterior annulus fibrosus or nucleus pulposus
5. Herniation of nucleus pulposus in the endplate
6. Debris in the disc space

Finally during a joint session the findings on MR images were compared with slides of the specimens.

Results

A total of 20 fractures were observed on anatomic sections (Table 1). In 12 of the discs adjacent to fractured vertebral bodies changes were seen on post-injury MR images in comparison with pre-injury MR images. Fracture lines usually extended from the endplates into the disc spaces. These were seen as low-signal lines through the disc space on the MR images. We called these lines "ruptures" to prevent any confusion with fractures. Parts of the endplate or the cancellous bone from the vertebral body were sometimes seen to be thrown into the disc space. These were seen as low-signal artefacts in the disc space on the MR images. We called these "debris". All of the changes seen from the pre- to the post-injury MR images corresponded to fresh injury to parts of the discs clearly discernible on anatomic sections. In discs that remained unchanged from pre- to post-injury MR images no evidence of fresh injury was found on anatomic sections. Most of the injuries were gross ruptures through the disc and were detected on all MR images. Even subtle changes on some of the discs, which were seen on anatomic sections as staining of the nucleus pulposus as a result of spraying of debris from the vertebral body following a minor fracture of the endplate, were detected on MR images as low-signal artefacts in the central part of the disc (Figs. 1–3). Some spontaneous reduction of the fractures was observed on post-injury MR images and the anatomic sections (Figs. 4, 5). All traumatic changes in the discs observed on the anatomic sections had been identified by the radiologist on the MR images. All changes identified on the MR images by the radiologist had been seen and reported on the anatomic sections. In the two

Table 1 Summary of the findings observed in the specimens. Discs and vertebrae numbered 1–6, with 1 being the most cranial. "Ruptures" denote fracture lines extending through disc space. "Debris" is substances from the bony endplate and the vertebral body within the confines of the disc space (*deg* degeneration, *ant* and *central* anterior and central one-third of the disc space)

	Specimen									
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
No. of vertebrae[a]	5	6	6	7	5	6	5	5	6	5
Fractured vertebrae	3,4	3,4	5	3,4,5,6	3	3,5	2	2,3,4	3,4,5	3
Injured discs	2,3	3	4	None	2	2,4,5	2	2	4	2
Disc 1	Pre-exist deg.	Pre-exist deg.	No injury	Pre-exist calcified	No injury	Pre-exist deg.	No injury	No injury	No injury	No injury
Disc 2	Rupture ant/central	Pre-exist deg.	Pre-exist Schmorl	Pre-exist deg.	Debris central	Debris central	Herniation in corpus	Debris central	No injury	Rupture ant.
Disc 3	Rupture central	Rupture ant.	No injury	Pre-exist deg.	No injury	Pre-exist deg.	No injury	No injury	No injury	No injury
Disc 4	No injury	No injury	Debris central	Pre-exist Schmorl	No injury	Rupture central	No injury	No injury	Rupture central	No injury
Disc 5	–	Pre-exist deg.	No injury	No injury		Rupture central			No injury	
Disc 6	–	–		No injury						

[a] In the specimen

specimens analysed in detail through volumetric MR acquisitions and micro-cryoplaning technique no evidence was found for kinds of injury that would not be detectable with the usual MRI and anatomic sections. H&E stained sections did not reveal any other findings not seen on non-stained sections.

The injury patterns observed varied greatly. Many of the fractures resembled injuries observed in clinical cases. For example, specimen 4, belonging to a 79-year-old woman with osteoporotic bone, showed four severe fractures of vertebral bodies without any injury to the adjacent discs. This pattern resembles clinical cases of osteoporotic fractures, with discs expanding into the fractured vertebral bodies. In specimen 7, from a 47-year-old man, the injury created a fracture resembling an incomplete burst fracture (AO classification [14], A 3.1), with the disc herniated into the endplate, but remaining contained within the cartilaginous endplate. In specimen 3, a fracture of the endplate that was hardly discernible on radiograms was associated with spraying of debris in the disc space (Fig. 2). If this is a pattern occurring in patients, it may explain unexpected severe course after some minor fractures. In all specimens the more severe fractures of the endplate and the vertebral body occurred adjacent to non-degenerative discs, confirming the earlier clinical and experimental observations [10, 20].

Discussion

Many types of injury to intervertebral discs are theoretically possible. If we consider the disc mechanism as consisting of the bony and cartilaginous endplates and a circumferential annulus, together containing a nucleus pulposus of mucoid material, we can imagine that this mechanism can be injured in many different ways. Different parts of this mechanism have probably different healing potentials. These factors may lead to variable modes of failure or healing. Bony endplate, which is the only structure detectable with conventional imaging techniques, may heal completely, but nevertheless lead to the disruption of the blood supply to the whole disc. The normal disc has an internal pressure higher than the surrounding tissues, because of osmotic differences created by the composition of the nucleus pulposus. This creates an expansive force that is contained by the bony endplates and the annulus. This structure, with high expansive capacity, may creep into the defects in the endplate and expand itself into the vertebral body. Clinical observations support the hypothesis that this may be an important mechanism for explanation of the changes observed in the disc space after a fracture [18]. Another mechanism may be a rapid disc degeneration initiated by an annular tear. Disruption of the annulus has been shown to lead to a rapid desiccation and degeneration of the whole disc in an animal model [19]. Finally, even if there is no change in the biological integrity of the disc, the changed morphology of the disc space as a result of the fracture of the vertebral body may alter its properties of resisting compressive forces. In a retrospective MRI study, Oner et al. showed that all these different mechanisms may lead to different types of post-traumatic disc space changes, with possible consequences for the long-term stability of the injured segment [18]. The question of whether these different

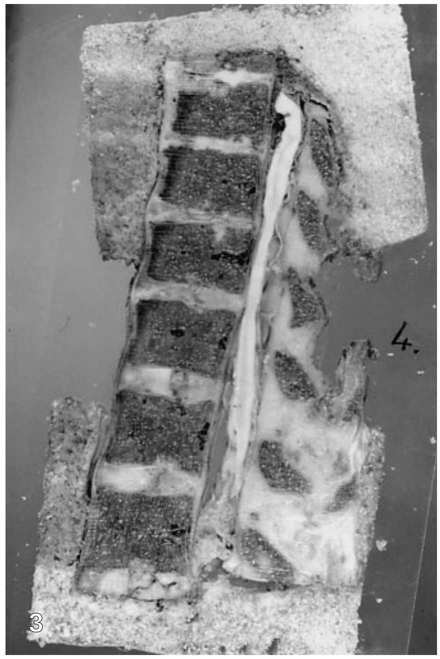

Fig. 1 Specimen 3. T2-weighted spin echo midsagittal image before injury

Fig. 2 The same specimen as Fig. 1, after injury. The small central endplate fracture was hardly discernible on radiograms. Note the low-signal area in the nucleus pulposus of disc 4 (the most cranial disc is disc 1)

Fig. 3 Corresponding anatomic section of specimen 3. Debris from the vertebral body is clearly seen in the nucleus pulposus of disc 4, corresponding to the low-signal area on the MR image

Fig. 4 Detail from the cryosection of specimen 6.The first (most cranial) disc on this photograph shows debris in the central area and a vertical rupture through the disc space. The second disc is pre-existing degenerative. The third and fourth discs show vertical ruptures through the central parts

Fig. 5 T2-weighted turbo spin echo image of the same specimen. All changes seen on the anatomical sections are discernible. The second disc corresponds to the first disc depicted in Fig. 4

mechanisms can be predicted from patterns of injury detected with MRI should be studied in a prospective fashion.

Although this study showed an excellent correlation between macroscopic damage to the disc and its MR images, we should recognize that the reality in a living subject can be much more complicated. Microscopic damage not discernible on anatomic sections and MR images or changes in the vascularity of the endplates can nevertheless have long-term consequences. Pre-existent changes in the discs such as Schmorl's or discopathy, which are in this study easily eliminated, will complicate the evaluation in clinical cases. Bleeding and oedema may lead to changes absent in a cadaver study. With all these limitations in mind, we can nevertheless conclude that MRI gives a reliable image of macroscopic injury to different sections of the disc on clinically applicable sequences and can be used in prospective clinical studies to determine injury patterns and their long-term consequences. In our clinic we have been using MRI for thoracolumbar spine fractures for some time, and our impression is that the images of endplate and disc disruptions created in this cadaver study resembled very closely the MR images seen in clinical cases.

In an experimental study, Kliewer et al. showed that injury to the ligaments associated with a thoracolumbar spine fracture can be reliably detected with MRI [11]. Our study shows that the injuries to intervertebral discs can also be reliably detected with MRI. These studies justify the use of MRI in the acute phase to for a detailed analysis of the injury patterns to structures undetectable with conventional imaging techniques, in order to investigate their possible prognostic consequences.

Recent attempts to at sophistication of classification systems aim to achieve higher degrees of prediction [14, 16]. Inclusion of injury patterns of non-osseous structures and the load-sharing capacity of the anterior column seem to be important aspects of the recent modifications of the classification systems to increase their prognostic power. Discs should be included in a comprehensive load-sharing classification system, because of their mechanical and biological properties. MRI studies can be used for this purpose.

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