ORIGINAL ARTICLE

Comparison of computed tomographic and magnetic resonance imaging in fracture healing after spinal injury

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Study design: Single-centre, prospective (comparative cohort) clinical study, with ethical approval and patient consent.

Objective: Confirmation of vertebral fracture union can pose significant challenges for clinicians in the management of spinal cord injury and in the decisions around patient mobilization. Bony union is usually assessed with computed tomography (CT). This study hypothesizes that magnetic resonance imaging (MRI) can identify vertebral bone union.

Setting: A major spinal injuries unit in the United Kingdom.

Method: Patients underwent CT and MRI at 12 weeks post-injury, if conservatively managed, or 12 weeks post-fixation. With CT as the gold standard, the MRI scans were reviewed blind to the CT result and indicators for fracture healing were compared.

Results: A total of 35 patients with 55 fractures were imaged. Comparison of CT and MRI showed sensitivity of 88%, specificity of 100% and positive predictive value of 100% for fracture union imaged with MRI using CT as the gold standard.

Conclusion: MRI correlates well with CT in identifying vertebral fracture union and non-union. We suggest that where imaging is indicated in the assessment of vertebral body fracture healing MRI can be used routinely with CT reserved for problematic or inconclusive cases.

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Introduction

Computed tomography (CT) provides a basis for highly accurate and precise assessment of the three-dimensional structural parameters of bone. However, metallic artefacts can produce image distortions and the repeated use of CT also causes a cumulative radiation dose effect for the patient. Many patients with spinal injuries are young and the dose implications are greater in this population than in the older age group.

Magnetic resonance imaging (MRI) has been used to evaluate for occult fractures and the presence of non-union. Fracture lines, continuity of marrow signal and the absence of bone marrow oedema as evidenced by signal change on MRI may indicate progression of fracture healing.

Vertebral union after fractures or incorporation of graft can be particularly difficult to assess. Altered sensation causes further limitation in clinical assessment. We hypothe-

size that MRI can contribute significantly to this assessment by observing absence of increased T2-weighted signal with union and bridging across the fracture site on T1-weighted images. A diagnostic method that does not use ionizing radiation would be of particular value.

Background

Bone undergoes constant remodelling influenced by chemical, mechanical, cellular and pathological mechanisms.¹ Fracture healing proceeds through an early inflammatory phase, a reparative phase of fibrosis, immature bone formation and a late reparative phase seen clinically as callus formation where reactive cartilage undergoes endochondral ossification.

The confirmation of vertebral fracture union can pose significant challenges for clinicians in the management of spinal cord injury. Significant union can be expected from 9 weeks post-injury or fixation, and around this time a decision may need to be taken with regard to mobilization of the patient. Although a clinical judgement can be made as to whether or not to mobilize at this stage, if there is clinical

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doubt then imaging is accepted practice to confirm bony union. This is usually assessed with plain radiographs but the identification of bridging callus can be very difficult. Many centres use CT for confirmation, but this carries a significant radiation burden.

This study hypothesizes that MRI can identify vertebral bone union. We define this as absence of any low signal fracture line showed on T1-weighted imaging and absence of high signal marrow oedema on T2-weighted imaging. We compare this with the standard of bridging trabecular bone on CT.

Patients and methods

This was a single-centre, prospective (comparative cohort) clinical study. The study was approved by the local ethics committee. Patients were given an information sheet and informed consent obtained.

Patients included were over 16 years old with a history of vertebral fracture, managed either conservatively or by internal fixation. Pregnant patients, and those with pacemakers, cochlear implants, ocular metal fragments and vascular clips were excluded from the study.

All patients underwent CT and MRI scans with an interval between them of <48 h. Imaging was performed at either 12 weeks post-injury in the conservatively managed group or 12 weeks post-surgery in the operatively managed group. The diagnosis of fracture healing was based on the presence of bridging trabecular bone across the fracture line on CT, and on the presence of normal T1-w marrow signal traversing the fracture line on MRI. The presence of a persisting fracture line on T1-w imaging, or surrounding oedema on T2-w imaging was considered to show that sufficient healing had not occurred.

Computed tomography images were obtained using a 16-detector row Siemens Sensation scanner (Erlangen, Germany) with a collimation of 1.25 mm, a table speed of 27.5 mm s⁻¹, 300 mAs, and 120 kVp. Multiplanar images were constructed and reviewed.

The MRI images were obtained on a 1.5 Tesla Siemens Symphony (Erlangen, Germany). Unenhanced sagittal T1-weighted and fat-suppressed (STIR) images were obtained in a sagittal plane.

At the time of reporting of the CT scan, a proforma was completed by the reporting radiologist. The MRI studies were reported blind to the CT result using a separate MRI proforma by a radiologist with an interest in spinal injuries (RW, TM, JW).

Results

A total of 35 patients with 55 fractures were recruited over 25 months. There were 16 cervical, 28 thoracic and 11 lumbar vertebral fractures.

There was correlation between CT and MRI in 45 of 55 fractures. In 40 cases, both CT and MRI showed fracture union. In five patients, there was evidence of non-union or active union on both CT and MRI (Table 1).

Table 1 Correlation of CT and MRI

CT	MRI		
	United	Not united	Total
United	40	6	46
Not united	0	5	5
Total	40	11	51

Abbreviations: CT, computed tomography; MRI, magnetic resonance imaging.

In six patients, there was evidence of a union on a CT scan but not on an MRI scan. Importantly, there were no fractures showing MRI criteria for union, which were not united on CT (Figure 1).

In a further four patients, there was no correlation between CT and MRI. In one that looked united on CT, the pedicle screw artefact made the MRI uninterpretable. In the other three, there was a mixed picture on MRI with some oedema but no clear fracture line and equivocal T1 findings.

Using the 51 analyzable fractures, correlation between CT and MRI for fracture union and non-union yields a sensitivity of 88%, specificity of 100% and a positive predictive value of 100% for MRI based on CT as a gold standard.

We found that artefact from pedicle screws can cause some difficulty in interpretation on MRI, but in five of the six cases with metal artefact sufficient marrow signal remains to determine outcome (Figure 2).

Discussion

Computed tomography is well established as a tool in the diagnosis of non-union after fracture.² High-resolution thin-slice CT images allow excellent depiction of trabecular and cortical morphology and provide a quantitative assessment of fracture healing.³ Although there has been limited use of MRI for the evaluation of fracture healing in the spine, MRI techniques have been validated for the assessment of trabecular and cortical bone structure with good reproducibility.⁴⁻⁶ MRI does have an established use in the diagnosis of occult fractures in the scaphoid bone using the presence of T1-weighted low signal and high signal on T2-weighted fat-suppressed imaging for diagnosis.^{7,8} MRI has also been used to evaluate for union in the femur and tibia.^{9,10}

Magnetic resonance imaging is also established in the diagnosis of both non-union of the scaphoid and of avascular necrosis after screw fixation.¹¹ This study describes artefact from the Herbert screws complicating imaging interpretation, but leaving sufficient signal in the proximal pole of the scaphoid for diagnosis. This is similar to our findings with pedicle screws in spinal fractures.

Singh *et al.*¹² used gadolinium-enhanced fat-suppressed sequences in the assessment of scaphoid fractures, particularly looking at vascularity and avascular necrosis; the additional benefit of gadolinium is not established but may be an area for further investigation in spinal fractures.

Figure 1 Healed fracture on CT and MRI. (a) CT, (b) T1-w MRI, (c) fat-suppressed (STIR) MRI.

Figure 2 Healed fracture on CT, equivocal on MRI. (a) CT, (b) T1-w MRI, (c) fat-suppressed (STIR) MRI.

The change in signal characteristics with time in vertebral compression fractures has been described by Sung *et al.*¹³ This shows T1-w hypointensity and T2-w hyperintensity in compression fractures <1 month old with signal returning to normal by 3 months. This evolution correlates well with our findings. MRI characteristics after fractures and pseudoarthrosis have also been described in patients with ankylosing spondylitis.¹⁴ Two patterns were identified on MRI: low T1-w and high T2-w signal as expected, but also some of the fractures showed low signal on both T1-w and T2-w imaging. This was thought to be because of fibrous union in a group of patients who had sustained a fracture in the earlier 18 months.

Fractures seen in spinal injuries are generally more complicated than in the above scenarios and frequently occur at more than one level. Our study has shown that the established MRI criteria for fracture healing can be generalized to the more complex spinal injury patient.

Our results suggest that replacing CT with MRI in the assessment of fracture union before mobilization is safe. There were no false negatives in our study. MRI seems to be better at assessing healing than non-healing fractures and in these cases CT will be needed. MRI also has the advantage that assessment of the spinal cord and any ligament or soft tissue damage can be made at the same time.

Conclusion

Magnetic resonance imaging correlates well with CT in identifying fracture union and non-union in 88% of cases.

In spinal cord injury, where the absence of sensation removes one of the physical parameters for gauging whether fixation has resulted in union, MRI is indicated in those instances when imaging is indicated, particularly in the younger patient group. Our study shows that if the established MRI criteria for fracture healing are used, including fracture lines, continuity of marrow signal and the absence of bone marrow oedema, that MRI correlates well with CT. MRI can be used routinely, thereby avoiding unnecessary radiation exposure to patients. CT can be reserved for problematic or inconclusive studies.

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