

Early magnetic resonance imaging compared with bone scintigraphy in suspected scaphoid fractures

F. J. P. Beeres,
S. J. Rhemrev,
P. den Hollander,
L. M. Kingma,
S. A. G. Meylaerts,
S. le Cessie,
K. A. Bartlema,
J. F. Hamming,
M. Hogervorst

*From Medical Centre
Haaglanden, The
Hague, The
Netherlands*

■ F. J. P. Beeres, MD, PhD,
Resident of Surgery
■ S. J. Rhemrev, MD, Trauma
Surgeon
■ P. den Hollander, MD,
Resident in Orthopaedics
■ L. M. Kingma, MD, PhD,
Radiologist
■ S. A. G. Meylaerts, MD, PhD,
Trauma Surgeon
Medical Centre Haaglanden,
Postbus 432, 2501 CK The
Hague, The Netherlands.
■ S. le Cessie, PhD, Statistician
■ K. A. Bartlema, MD, Trauma
Surgeon
■ J. F. Hamming, MD, PhD,
Professor, General Surgeon
Leiden University Medical
Centre, Postbus 9600, 2300 RC
Leiden, The Netherlands.
■ M. Hogervorst, MD, Trauma
Surgeon
Gelre Ziekenhuizen, Postbus
9014, 7300 DS Apeldoorn, The
Netherlands.

Correspondence should be sent
to Dr F. J. P. Beeres; e-mail:
f.j.p.beeres@lumc.nl

©2008 British Editorial Society
of Bone and Joint Surgery
doi:10.1302/0301-620X.90B9.
20341 \$2.00

J Bone Joint Surg [Br]
2008;90-B:1205-9.
Received 16 October 2007;
Accepted after revision 12 May
2008

We evaluated 100 consecutive patients with a suspected scaphoid fracture but without evidence of a fracture on plain radiographs using MRI within 24 hours of injury, and bone scintigraphy three to five days after injury. The reference standard for a true radiologically-occult scaphoid fracture was either a diagnosis of fracture on both MRI and bone scintigraphy, or, in the case of discrepancy, clinical and/or radiological evidence of a fracture.

MRI revealed 16 scaphoid and 24 other fractures. Bone scintigraphy showed 28 scaphoid and 40 other fractures. According to the reference standard there were 20 scaphoid fractures. MRI was falsely negative for scaphoid fracture in four patients and bone scintigraphy falsely positive in eight. MRI had a sensitivity of 80% and a specificity of 100%. Bone scintigraphy had a sensitivity of 100% and a specificity of 90%.

This study did not confirm that early, short-sequence MRI was superior to bone scintigraphy for the diagnosis of a suspected scaphoid fracture. Bone scintigraphy remains a highly sensitive and reasonably specific investigation for the diagnosis of an occult scaphoid fracture.

Ever since its description in 1905,¹ the diagnosis of a suspected scaphoid fracture has been a problem. Patients with a history of acute trauma, clinical signs of a scaphoid fracture but no evidence of fracture on plain radiographs will have a fracture in up to 25% of cases.²⁻⁵ These occult fractures can lead to complications, such as osteonecrosis, non-union, carpal instability and functional impairment,⁶⁻¹¹ and a delay in treatment increases this risk. There is a clear need for a fast and reliable method of diagnosis in order to initiate appropriate treatment as quickly as possible.

Bone scintigraphy has been widely used in the diagnosis of scaphoid fractures. It has a sensitivity of approximately 95% and a specificity of between 60% and 95%.^{5,6,11,12} However, it requires intravenous radioactive isotopes and a delay of at least 72 hours after injury. It involves a radiation dose of 4 mSv, which is equivalent to two years of natural background radiation. Alternative imaging is therefore being investigated. CT has been reported to be a useful technique, but false positive results occur when it is used acutely for scaphoid fractures.¹³ Compared with bone scintigraphy, however, it is insensitive.¹⁴

The American College of Radiology currently considers MRI and plain radiographs to be the most appropriate investigations for

imaging acute scaphoid fractures.¹⁵ It is suggested that the sensitivity and specificity of MRI are approximately 100%.^{4,12,16-19} The Royal College of Radiologists in the United Kingdom gives equal weight to MRI, CT and bone scintigraphy in the imaging of acute scaphoid injuries when plain radiographs are negative.²⁰ At present there is insufficient scientific evidence regarding the ideal imaging technique for acute scaphoid trauma.²¹

The value of MRI in the detection of suspected scaphoid fractures has not been evaluated properly. In particular, early MRI has not been compared with bone scintigraphy. This is important, because early MRI could obviate many of the disadvantages of bone scintigraphy. The object of the present study was to determine whether early MRI was superior to bone scintigraphy for suspected scaphoid fractures.

Patients and Methods

This prospective study was conducted with the consent of the Regional Ethical Committee. Between March 2004 and January 2007, 100 consecutive patients who attended the Accident and Emergency Department with a suspected scaphoid fracture were included in the study. Patients were eligible if they consented to participate, had a suspected scaphoid fracture (tender in the anatomical snuffbox, and

pain in the snuffbox when applying axial pressure to the thumb or index fingers, a recent injury (within 48 hours), and no evidence of a fracture on plain radiographs. Polytrauma patients, patients under the age of 18 years, and those in whom MRI was contraindicated were excluded.

After inclusion in the study all patients had a physical examination. MRI of the hand and wrist was performed within 24 hours after initial presentation to the Accident and Emergency Department. Bone scintigraphy of the hand and wrist was performed three to five days after injury.

In the Accident and Emergency Department, and at fixed intervals throughout follow-up, the patients were physically examined. They were asked to localise the 'point of maximal tenderness' and both wrists and hands were examined. Pressure was applied to the anatomical snuffbox, distal radius and carpal bones. Axial pressure was then applied to both the thumb and index finger. A scaphoid fracture was clinically suspected if there was a tender anatomic snuffbox and pain in the snuffbox when axial pressure was applied. Finally, flexion and extension of the wrist were measured. All examinations were performed blind to the results of previous examinations, MRI, bone scintigraphy and scaphoid radiographs.

Initial scaphoid radiographs were carried out in three planes: a posteroanterior view with the hand in a neutral position; an oblique view with the wrist in 10° of supination and maximal ulnar deviation; and a true lateral view with the wrist resting in the ulnar position on the X-ray plate. Initially all radiographs were assessed by the duty surgeon in the Accident and Emergency Department and a duty radiologist. Subsequently the radiographs were examined by a consultant trauma surgeon and a consultant radiologist. In order to be eligible for inclusion in the study, all responses had to be negative for a scaphoid fracture.

A 1.5 Tesla MR scan (Siemens, Erlangen, Germany) was used. The patient lay prone on the scanner couch with the hand suspected of a scaphoid fracture extended forward palm down over the patient's head. A flexible surface coil was wrapped around the wrist. The MR imaging protocol included coronal T₁-weighted turbo spin-echo images with a TR of 450 ms, a TE of 13 ms, a field view of 180 mm, a base resolution of 512, two averages, a slice thickness of 3 mm with a distance factor of 10%, and a scan time of 2.17 minutes. The parameters for the coronal fat-suppressed T₂-weighted fast spin-echo images were 5220/73 ms (TR/TE), a field of view of 220 mm, a base resolution of 448, three averages, a slice thickness of 3 mm with a distance factor of 10%, and a scan time of 4.33 minutes.

Bone scintigraphy was performed within three and five days after injury using a standard protocol of images of the early static phase, on a Sky-Light gamma camera (Philips, Eindhoven, The Netherlands). Palmar and dorsal images of both wrists were taken in every patient between two and a half and four hours after the injection of 500 MBq of technetium-99m diphosphonate (99mTc-HDP) to visualise osteoblast activity.

A trainee and a consultant radiologist evaluated the MR scans, and a consultant clinical nuclear physician evaluated the bone scans. For both types of scan, observers filled in a standard form, blind to each other and blind to any other data, which was scored as follows:

1. Scaphoid fracture (yes/no).
2. Other fracture (yes/no).

The radiologist also evaluated the presence or absence of a soft-tissue injury.

Patients with a scaphoid fracture on either MRI or bone scintigraphy were treated with a scaphoid forearm cast (a below-elbow cast incorporating the thumb in the anatomical position as far as the interphalangeal joint) for six weeks.

In patients where clinical signs of a fracture remained after the standard immobilisation period of six weeks, a new cast was applied for a further two weeks. This procedure was repeated every two weeks (maximum of 12 weeks) until there were no longer any clinical signs of a fracture.

Patients with a scaphoid fracture on either MRI or bone scintigraphy were clinically re-examined at two, six and eight weeks after injury, and then at three and six months. Standard scaphoid radiographs were taken six weeks after injury. Final discharge was at least six months after injury, but no radiographs were taken if the patient was painfree and had normal wrist function.

Patients with other fractures were treated according to the local trauma protocol and discharged at least ten weeks after injury. Patients with no evidence of a fracture on both MRI or bone scintigraphy were treated with a supportive bandage and reassessed two and six weeks after injury.

A final diagnosis was made after final discharge according to the following reference standard.

If MRI and bone scintigraphy both showed a fracture, the final diagnosis was: fracture.

If MRI and bone scintigraphy both showed no fracture, the final diagnosis was: no fracture.

Where there was a discrepancy between MRI and bone scintigraphy, plain radiographs (six weeks after injury) and physical examination during follow-up were used to make the final diagnosis.

If any clinical sign remained abnormal after two weeks (tenderness in the anatomical snuffbox or pain when applying axial pressure to the thumb or index finger) and/or there was radiological evidence of a fracture six weeks after injury, the final diagnosis was: fracture.

If there were no clinical signs after two weeks (no tenderness or pain in the snuffbox when applying axial pressure to the thumb or index finger) or no radiological evidence of a fracture six weeks after injury, the final diagnosis was: no fracture.

Statistical analysis. The following assumptions were used to calculate the power of the study. According to the literature, 25% of the cases with a scaphoid fracture will have no evidence of a fracture on radiographs.²⁻⁵ The sensitivity of bone scintigraphy is approximately 95% and the specificity around 70%.^{5,6,11,12} This can be translated into a suspected

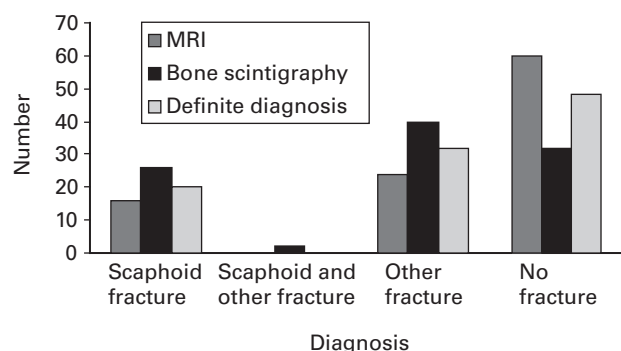


Fig. 1

Bar chart showing the results of MRI, bone scintigraphy and final diagnosis of 100 patients with a suspected scaphoid fracture but no evidence of a fracture on radiographs.

chance of a correct diagnosis on bone scintigraphy of 0.7625 ($0.25 \times 0.95 + 0.75 \times 0.70$). Our hypothesis was that MRI had an equal sensitivity but a specificity of 90%.^{4,6,12,16-19,22} This gave a chance of 0.9125 ($0.25 \times 0.95 + 0.75 \times 0.90$) of a correct diagnosis using MRI.

In order to detect this difference in correct diagnosis with a power of 0.80 using a McNemar test ($\alpha = 0.05$, two-tailed), 108 patients are needed if the results of the MRI and bone scintigraphy do not correlate with a patient. It is very likely that there is a positive correlation between the results of MRI and bone scintigraphy, meaning the number of patients can be reduced. Therefore the aim was to include 100 patients.

According to the reference standard, the sensitivity and specificity were calculated for bone scintigraphy and MRI scan. Finally, percentages of correct predictions between the two diagnostic methods were compared with a McNemar test. A p -value < 0.05 was considered significant.

Results

The study population consisted of 100 patients, 50 men and 50 women. Their mean age was 42 years (18 to 84). The dominant hand was injured in 48, and 11 had a previous injury to the hand or wrist (five ipsilateral and six contralateral side). All had a clinically-suspected scaphoid fracture, but initial radiographs showed no evidence of a fracture.

MRI showed 16 scaphoid fractures and 24 other fractures (13 carpal and 11 distal radial fractures). A soft-tissue injury was seen in three patients. Bone scintigraphy showed 28 scaphoid fractures and 40 other fractures (27 carpal, 11 distal radial, one metacarpal and one ulnar fracture). According to the final diagnosis there were 20 scaphoid fractures and 32 other fractures (Fig. 1).

MRI was false negative in four patients with a scaphoid fracture and bone scintigraphy was false positive in eight patients without a scaphoid fracture. MRI had a sensitivity

Table I. True and false scans for a scaphoid fracture. Sensitivity, specificity, positive and negative predictive value of MRI and bone scintigraphy for the detection of occult scaphoid fracture (95% confidence intervals in parentheses)

Scaphoid fracture	MRI	Bone scintigraphy
True positive	16	20
True negative	80	72
False positive	0	8
False negative	4	0
Sensitivity (%)	80 (56 to 94)	100 (83 to 100)
Specificity (%)	100 (96 to 100)	90 (81 to 96)
Positive predictive value (%)	100 (74 to 100)	71 (52 to 87)
Negative predictive value (%)	95 (88 to 99)	100 (95 to 100)

of 80% (16 of 20) and a specificity of 100% (80 of 80). Bone scintigraphy had a sensitivity of 100% (20 of 20) and a specificity of 90% (72 of 80). Bone scintigraphy predicted 92 scans correctly and eight scans incorrectly, whereas MRI was correct in 96 patients and false in four (Table I). In the eight patients with false positive bone scintigraphy all follow-up radiographs were normal and showed no evidence of a fracture. Two of the four patients with false negative MR scans had clear fractures on follow-up radiographs. The radiographs of the other two patients with false negative MR scans did not clearly show a scaphoid fracture. There was no significant difference between the percentage of correct predictions with MRI and bone scintigraphy ($p = 0.388$).

The results of the MRI and the final diagnosis of the eight patients with a false positive bone scan are shown in Table II.

All patients were symptom-free and had good hand and wrist function at discharge (at least six months for scaphoid fractures). Clinical examination at discharge showed no evidence of a nonunion. All patients with a fracture went on to clinical union and none of the fractures were internally fixed.

Discussion

A total of 20 patients (20%) had a scaphoid fracture that was not seen on the plain radiographs. Four of these fractures were also not seen on MRI. Bone scintigraphy gave a false positive in eight patients. In five of these there was a traumatic lesion (i.e. other fracture, ligament tear or bone bruise) but no scaphoid fracture.

Many authors have suggested MRI as the investigation of choice for the detection of occult scaphoid fractures.^{4,12,15-19} In the literature, only four papers have compared (delayed) MRI and bone scintigraphy for suspected scaphoid fractures.^{12,22-24} These papers all used different imaging sequences and protocols, and suggested that MRI was superior to bone scintigraphy. The maximum number of patients in any of these studies was 59.²² A total of 145 patients were used to compare the two imaging modalities

Table II. Results of the MR scans and final diagnosis of the eight patients with a false positive bone scintigraphy for a scaphoid fracture

	Bone scintigraphy	MRI	Final diagnosis
1	Scaphoid fracture	Bone bruise scaphoid	No fracture
2	Scaphoid fracture	Bone bruise scaphoid	No fracture
3	Scaphoid fracture	Triquetral fracture	Carpal fracture
4	Scaphoid fracture	Distal radial fracture	Distal radial fracture
5	Scaphoid fracture	Triangular ligament tear	No fracture
6	Scaphoid fracture	Subcortical scaphoid cyst	No fracture
7	Scaphoid fracture	No injury	No fracture
8	Scaphoid fracture	No injury	No fracture

in the four studies. In three of these papers MRI was delayed until at least ten days after injury.^{12,22,24} In the fourth paper, MRI was performed at a mean of 10 days (3 to 14) after injury.²³ None of these studies used a standardised algorithm, independent of diagnostic results, to define the final diagnosis and compare the results between MRI and bone scintigraphy. We believe this is the largest series to date comparing MRI with bone scintigraphy, and that it is the first series to assess the value of early (i.e., within 24 hours of presentation) MRI for occult scaphoid fractures.

All MR scans were performed within 24 hours after presentation to the Accident and Emergency Department, and within a maximum of three days after injury. In order to assess a fast protocol that could be easily implemented in daily practice, this study only used a coronal imaging MRI protocol and a relatively large field of view. Scanning time was less than seven minutes, so that it could be used in a busy daily clinic. The fractures in patients with a false negative MR scan might have been demonstrated by additional views or additional sequences. It is possible that the low incidence of soft-tissue injuries detected was due to the MRI protocol employed. It might be useful to perform additional sequences on patients without an evident fracture on MRI to detect fractures in an unusual plane or soft tissue or ligamentous injuries. The early and limited scanning protocol could explain the lower sensitivity of MRI in this study.

The determination of a reference standard was challenging. In cases of equivocal imaging studies we used clinical and radiological follow-up (six weeks after injury) to determine the final diagnosis. According to the literature, each clinical sign in the physical examination has a sensitivity approximating 100% for the diagnosis of scaphoid fractures.²⁵⁻²⁸ Also, when combined with the clinical signs, physical examination has a high specificity up to 98%, which is further enhanced by serial examinations.²⁵⁻²⁸ Physical examination also enables distinction between a scaphoid and a different fracture. However, it is difficult to distinguish clinically between a scaphoid fracture and adjacent soft-tissue injury, but there were no soft-tissue injuries seen in any of the four false negative MR scans. It is therefore unlikely that scaphoid fractures were missed

throughout clinical and radiological follow-up. This is supported by the finding that no symptomatic pseudarthrosis occurred within the six-month follow-up period. However, no standard plain radiographs were performed six months after injury to confirm or rule out an asymptomatic nonunion. There are surgeons who suggest the use of late radiographs as the final arbiter.¹³ Consequently, the two patients with a false negative MR scan (clinically suspected, negative initial and follow-up radiographs, negative MR scan, positive bone scintigraphy and positive clinical follow-up) could be considered to have a correct MR scan and a false positive bone scan when using late radiographs as the definitive assessment of fracture.

The results concerning other fractures show a trend similar to scaphoid fractures, but are beyond the scope of this study and will not be discussed.

Occult scaphoid fractures can be challenging and a delay in treatment increases the risk of complications. This creates a tendency to overtreat patients with a suspected scaphoid fracture. There is a need for a fast and adequate diagnostic protocol in order to start appropriate treatment as soon as possible. A false positive outcome is therefore preferred to a false negative. MRI has been suggested as the investigative technique of choice for occult scaphoid fractures,^{4,12,15-19} and appears to be more specific and able to give more information on soft-tissue injuries. Early MRI with a short-sequence technique proved to have a very high specificity but a lower sensitivity for scaphoid fractures. The use of early MRI as the sole imaging tool will run the risk of undertreating these patients. Bone scintigraphy had a sensitivity of 100% but gave a false positive for a scaphoid fracture in 8% of patients, which would lead to overtreatment of these patients. However, overtreatment is still preferred to undertreatment of these fractures.

In conclusion, this study did not confirm that early, short-sequence MRI was superior to bone scintigraphy for the detection of suspected scaphoid fractures. Despite the radiation dose, bone scintigraphy remains the investigation of choice in the diagnosis of clinically suspected scaphoid fractures where plain radiographs have been unhelpful.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References

1. Destot E. Injuries of the wrist: a radiologic study. Paris, Vitot Freres, 1905.
2. Beeres FJ, Hogervorst M, Rhemrev SJ, de Hollander P, Jukema GN. A prospective comparison for suspected scaphoid fractures: bone scintigraphy versus clinical outcome. *Injury* 2007;38:769-74.
3. Beeres FJ, Hogervorst M, den Hollander P, Rhemrev S. Outcome of routine bone scintigraphy in suspected scaphoid fractures. *Injury* 2005;36:1233-6.
4. Brydie A, Raby N. Early MRI in the management of clinical scaphoid fracture. *Br J Radiol* 2003;76:296-300.
5. Gaebler C, Kukla C, Breitenseher M, et al. Magnetic resonance imaging of occult scaphoid fractures. *J Trauma* 1996;41:73-6.
6. Bayer LR, Widding A, Diemer H. Fifteen minutes bone scintigraphy in patients with clinically suspected scaphoid fracture and normal x-rays. *Injury* 2000;31:243-8.
7. Cooney WP 3rd. Scaphoid fractures: current treatments and techniques. *Instr Course Lect* 2003;52:197-208.
8. Krasin E, Goldwirth M, Gold A, Goodwin DR. Review of the current methods in the diagnosis and treatment of scaphoid fractures. *Postgrad Med J* 2001;77:235-7.
9. Prosser GH, Isbister ES. The presentation of scaphoid non-union. *Injury* 2003;34:65-7.
10. Roolker W, Maas M, Broekhuizen AH. Diagnosis and treatment of scaphoid fractures, can nonunion be prevented? *Arch Orthop Trauma Surg* 1999;119:428-31.
11. Tiel-van Buul MM, Rookler W, Broekhuizen AH, Van Beek EJ. The diagnostic management of suspected scaphoid fracture. *Injury* 1997;28:1-8.
12. Fowler C, Sullivan B, Williams LA, et al. A comparison of bone scintigraphy and MRI in the early diagnosis of the occult scaphoid waist fracture. *Skeletal Radiol* 1998;27:683-7.
13. Adey L, Souer JS, Lozano-Calderon S, et al. Computed tomography of suspected scaphoid fractures. *J Hand Surg [Am]* 2007;32:61-6.
14. Tiel-van Buul MM, van Beek EJ, Dijkstra PF, et al. Significance of a hot spot on the bone scan after carpal injury: evaluation by computed tomography. *Eur J Nucl Med* 1993;20:159-64.
15. No authors listed. American College of Radiology (ACR), Expert Panel on Musculoskeletal Imaging, ACR Appropriateness Criteria. Acute hand and wrist trauma. Reston: American College of Radiology, 2001:1-7.
16. Breitenseher MJ, Metz VM, Gilula LA, et al. Radiographically occult scaphoid fractures: value of MR imaging in detection. *Radiology* 1997;203:245-50.
17. Hunter JC, Escobedo EM, Wilson AJ, et al. MR imaging of clinically suspected scaphoid fractures. *AJR Am J Roentgenol* 1997;168:1287-93.
18. Memarsadeghi M, Breitenseher MJ, Schaefer-Propok C, et al. Occult scaphoid fractures: comparison of multidetector CT and MR imaging: initial experience. *Radiology* 2006;240:169-76.
19. Nikken JJ, Oei EH, Ginai AZ, et al. Acute wrist trauma: value of a short dedicated extremity MR imaging examination in prediction of need for treatment. *Radiology* 2005;234:116-24.
20. No authors listed. Royal College of Radiologists. Making the best use of clinical radiology services: referral guidelines. Sixth ed. London, UK: Royal College of Radiologists, 2007.
21. Groves AM, Kayani I, Syed R, et al. An international survey of hospital practice in the imaging of acute scaphoid trauma. *AJR Am J Roentgenol* 2006;187:1453-6.
22. Thorpe AP, Murray AD, Smith FW, Ferguson J. Clinically suspected scaphoid fracture: a comparison of magnetic resonance imaging and bone scintigraphy. *Br J Radiol* 1996;69:109-13.
23. Tiel-van Buul MM, Roolker W, Verbeeten BE, Broekhuizen AH. Magnetic resonance imaging versus bone scintigraphy in suspected scaphoid fracture. *Eur J Nucl Med* 1996;23:971-5.
24. Kitsis C, Taylor M, Chandey J, et al. Imaging the problem scaphoid. *Injury* 1998;29:515-20.
25. Grover R. Clinical assessment of scaphoid injuries and the detection of fractures. *J Hand Surg [Br]* 1996;21:341-3.
26. Parvizi J, Wayman J, Kelly P, Moran CG. Combining the clinical signs improves diagnosis of scaphoid fractures: a prospective study with follow-up. *J Hand Surg [Br]* 1998;23:324-7.
27. Steenvoorde P, Jacobi C, van Doorn L, Oskam J. Pilot study evaluating a clinical decision tool on suspected scaphoid fractures. *Acta Orthop Belg* 2006;72:411-14.
28. Waeckerle JF. A prospective study identifying the sensitivity of radiographic findings and the efficacy of clinical findings in carpal navicular fractures. *Ann Emerg Med* 1987;16:733-7.