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ORIGINAL ARTICLE

Comparison of MRI, CT and bone scintigraphy for suspected scaphoid fractures

A. D. de Zwart[1,4] · F. J. P. Beeres[2] · S. J. Rhemrev[3] · K. Bartlema[1] · I. B. Schipper[1]

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Abstract
Purpose The best diagnostic modality for confirmation of the diagnosis of a scaphoid fracture that is not visible on the initial radiograph (occult scaphoid fracture) is still subject of debate. The aim of this study was to compare the accuracy of magnetic resonance imaging (MRI), computed tomography (CT) and bone scintigraphy (BS) for the diagnosis of these occult scaphoid fractures.
Patients and methods In a study period of 12 months, 33 consecutive patients with a clinically suspected scaphoid fracture without a fracture on the scaphoid radiographs were evaluated with MRI, CT and BS. In case of a discrepancy between the diagnostic modalities, the final diagnosis was based on standardised follow-up with clinical examination and a repeated radiograph.
Results Three of the 33 patients had a scaphoid fracture. MRI missed one scaphoid fracture and did not over-diagnose. CT missed two scaphoid fractures and did not over-diagnose. BS missed no scaphoid fractures and over-diagnosed one scaphoid fracture in a patient with a fracture of the trapezium.
Conclusion This study shows that neither MRI, nor CT and BS are 100 % accurate in diagnosing occult scaphoid fractures. MRI and CT miss fractures, and BS tends to over-diagnose. The specific advantages and limitations of each diagnostic modality should be familiar to the treating physicians and taken into consideration during the diagnostic process.

Keywords Scaphoid fracture · MRI · CT · Bone scintigraphy

✉ A. D. de Zwart
p.krijnen@lumc.nl

1 Department of Surgery, Leiden University Medical Centre, Postbus 9600, 2300 RC Leiden, The Netherlands

2 Deparment of Surgery, Luzerner Kantonsspital, 6006 Lucerne, Switzerland

3 Department of Surgery, Medical Centre Haaglanden, 2512 VA The Hague, The Netherlands

4 Department of Trauma Surgery, Leiden University Medical Centre, Leiden, The Netherlands

Introduction

Fractures of the scaphoid are the second most common fractures of the upper limb after distal radius fractures [1, 2]. Rapid and accurate diagnosis is needed, because delayed initiation of therapy increases the risk of complications such as non-union and avascular necrosis, and subsequent functional impairment [3–6]. The diagnosis of a scaphoid fracture may however be difficult to establish on a conventional radiograph. Previous research has shown that 10 % of scaphoid fractures are missed on primary radiographs [7–9]. Repeated radiographs after 7–10 days seem to have limited value, without additional diagnostics [10–12]. The irregular contour, the 3-dimensional location in the wrist of the scaphoid and the overlap of the carpal bones render interpretation of scaphoid radiographs difficult, especially in the absence of fracture dislocation. Magnetic resonance imaging (MRI), computed tomography (CT) and bone scintigraphy (BS) have been shown to have better diagnostic performance than scaphoid radiographs [13]. However, it remains subject of debate which of these three is the most appropriate and accurate modality for the diagnostic work-up of a clinically suspected scaphoid fracture. To our knowledge, no prospective study has been performed comparing diagnostic accuracy of MRI in the acute

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stage (<72 h), CT in the acute stage (<72 h) and delayed BS (between 3 and 5 days) in one patient series. For this reason we compared MRI, CT and BS in a consecutive series of patients with a clinical suspicion of a scaphoid fracture and a negative radiograph.

Patients and methods

This prospective study was approved by the regional Medical Ethics Committee.

Patients were eligible if there was a clinical suspicion of a scaphoid fracture, a recent hand trauma (within 48 h) and no evidence of a scaphoid fracture on the initial scaphoid radiographs. All consecutive eligible patients that visited the Emergency Department (ED) of our institution were included for extensive diagnostic work-up after both written and oral informed consent. Poly-trauma patients, patients with a history of a carpal fracture, patients younger than 18 years and patients with contra-indications for MRI, CT or BS were excluded.

Physical examination

Included patients underwent a standardised physical examination of both wrists and hands at the ED. Patients were asked to localise the "point of maximal tenderness" for pain. Direct pressure was applied on the anatomic snuffbox, distal radius and other carpal bones. Axial pressure was applied on both the first and second digit. All patients were clinically re-examined at 2 and 6 weeks after injury.

Scaphoid radiographs

All radiographs were obtained using a digital technique and a computed radiography system (Siemens Vertex 3D, Erlangen, Germany). Initial scaphoid radiographs were taken in six planes: (1) a postero-anterior view with the hand 5 degrees of endorotation, (2) a true lateral view with the wrist resting in the ulnar position on the X-ray plate, (3) an oblique view with the radius 30° up, (4) an oblique view with the radius 60° up, (5) an antero-posterior view in ulnar deviation and (6) a postero-anterior view with the thumb in fist. Standard scaphoid radiographs were made within 48 h after trauma and repeated after 6 weeks.

MRI

MRI was performed within 72 h after the initial presentation at the ED using a 1.5 T MR scan (GE/ONI MSK Extreme). The patient lay prone on the scanner couch with the injured hand extended forward palm down over the patient's head. The MR imaging protocol included coronal $T1$-weighted turbo spin-echo images with a TR of 450 ms, a TE of 13 ms, a slice thickness of 2 mm with a distance factor of 10 %. The parameters for the coronal, oblique and sagittal fat-suppressed $T2$-weighted fast spin-echo images were 5220/73 ms (TR/TE). A slice thickness of 2 mm with a distance factor of 10 % was used.

CT

The CT scans were obtained within 72 h after the initial presentation at the Emergency Department with a Toshiba 64 slice scanner using the technique described by Sanders [14]. Slice thickness was 0.5 mm with reconstructions every 0.3 mm (120 per kV, 60 mA). For multi-planar reformatted images, parameters were 2 mm slice thickness, 2 mm interval. Sagittal and coronal reconstructions were made for all CT scans.

Bone scintigraphy

Bone scintigraphy was performed between 3 and 5 days after trauma, using a standard protocol of images of the early static phase, on a SKYLight gamma camera (Philips, Eindhoven, the Netherlands). Palmar and dorsal images of both wrists were performed between two and a half and four hours after the intravenous injection of 500 MBq of Tc-99 m-HDP (Technetium-99 m hydroxymethylene diphosphonate) visualising the osteoblastic activity with a planar collimator. Each imaging process took 10 min.

Image analysis

All radiographs were reviewed by the attending resident surgeon in the ED and decided if the patient was suitable for inclusion. A consultant radiologist evaluated the MRI and CT images.

A consultant nuclear medicine physician evaluated the BS. The observers were blinded to the results of the other investigations. The presence of a scaphoid fracture, of other fractures, of arthrosis, and of other lesions on CT, MRI and BS was scored by the observers on a standard yes/no format form.

Management of injury

If all diagnostic modalities were negative for fracture, no immobilisation therapy was applied. If at least one of the diagnostic modalities showed a scaphoid fracture, the patient was treated with a scaphoid forearm cast for a period of 6 weeks. If one of the diagnostic modalities showed another type of fracture, the patient was treated according to the specific protocol.

Reference standard

The final diagnosis of presence or absence of a scaphoid fracture was confirmed after follow-up according to the following reference standard.

- If MRI, CT and BS all showed a fracture, the final diagnosis was: fracture.
- If MRI, CT and BS all showed no fracture, the final diagnosis was: no fracture.

In case of discrepancy between MRI, CT and BS, the final diagnosis was established based on specific clinical signs of a fracture after 6 weeks (tender anatomic snuffbox and pain in the snuffbox when applying axial pressure on the first or second digit) combined with the radiographic evidence of a fracture after 6 weeks. If these signs were absent and no radiographic evidence, the final diagnosis was: no fracture.

Results

Between May 2010 and May 2011, 43 consecutive patients with a suspected scaphoid fracture visited the Emergency Department. A scaphoid fracture was apparent on initial radiographs of nine patients. The 34 patients with a clinically suspected scaphoid fracture and negative radiographs were included for extensive diagnostic work-up after providing informed consent. One patient was excluded as no CT was made. The remaining study group of 33 patients consisted of 16 men and 17 women, with a mean age of the 39 years (range 18–73).

Table 1 Diagnoses according to MRI, CT, and BS in 33 patients with clinical suspicion of a scaphoid fracture and negative scaphoid radiographs

Diagnosis	MRI	CT	BS
Scaphoid fracture	2	1	4
Other fracture	11	11	10
No injury	20	21	19

An overview of the diagnosed scaphoid and other fractures by MRI, CT and BS is given in Table 1.

In four patients one or more diagnostic modalities showed a scaphoid fracture.

According to the reference standard there were three scaphoid fractures. In one patient MRI and CT showed a trapezium fracture whereas BS showed a scaphoid fracture, which we considered as false positive for scaphoid fracture (Table 2). The calculation of sensitivity of the diagnostic modalities for three scaphoid fractures was not considered meaningful. The specificity for diagnosis of occult scaphoid fractures was 100 % (95 % CI 0.88–1) for MRI, 100 % (95 % CI 0.88–1) for CT and 97 % (95 % CI 0.83–1) for BS.

In 11 of the 33 patients with clinically suspected scaphoid fractures, other injuries than scaphoid fractures were diagnosed. Eight were distal radius fractures that had been visualized by all three diagnostic modalities. In one patient a distal radius fracture was diagnosed by BS and MRI, but with a negative CT. There was one patient with a triquetrum fracture diagnosed by all three additional diagnostic modalities, and one patient had a trapezium fracture as mentioned above (CT and MRI showed a trapezium fracture and BS a scaphoid fracture).

Thus, combined with the scaphoid fracture patients, in 14 of the 33 suspected patients, additional immobilisation therapy was instituted based on the findings of MRI, CT and BS.

Discussion

This study is unique, as it is the first clinical study comparing CT, MRI and BS for diagnosis in suspected scaphoid fractures in one patient series. The results show that these sophisticated imaging methods diagnose scaphoid fractures in 10 % of patients with negative initial scaphoid radiographs. In addition, in 25 % of the patients another fracture in the same anatomical area was revealed.

Many studies have separately examined the results of MRI, CT and BS for diagnosing suspected scaphoid fractures. A meta-analysis of diagnostic studies was performed by Yin et al. (2010), in which the pooled sensitivities and

Table 2 Diagnostic results for the patients in whom one or more diagnostic modalities showed a scaphoid fracture including the clinical follow up at 6 weeks and the repeated radiograph

	MRI	CT	BS	X-ray[a]	PE	Final diagnosis
1.	No injury	No injury	Scaphoid fx	No injury	Scaphoid fx	Scaphoid fx
2.	Scaphoid fx	Scaphoid fx	Scaphoid fx	Scaphoid fx	No injury	Scaphoid fx
3.	Scaphoid fx	No injury	Scaphoid fx	No injury	Scaphoid fx	Scaphoid fx
4.	Trapezium fx	Trapezium fx	Scaphoid fx	No injury	No injury	Trapezium fx

PE physical examination, *fx* fracture

[a] At 6 weeks after injury

Table 3 Overview of relevant literature concerning diagnostic performance of CT, MRI and BS in suspected scaphoid fractures

Study	Number of patients	Sensitivity (%)	Specificity (%)
CT			
Yin et al. (meta-analysis)	211	93	99
Ilica et al.	54	86	100
Mallee et al.	34	67	89
Rhemrev et al.	100	64	99
BS			
Yin et al. (meta-analysis)	1102	97	89
Rhemrev et al.	100	93	91
Buijze et al.[a]	78	100	89
MRI			
Yin et al. (meta-analysis)	513	96	99
Mallee et al.	34	67	96
Buijze et al.[a]	78	75	100

[a] In this study sensitivities and specificities were calculated using latent class analysis and with a conventional reference standard (repeated radiograph). In this table we used the results of conventional reference standard

specificities of MRI, CT and BS were calculated [13]. Since this study, four additional prospective studies have been published concerning the diagnostic performance of CT and/or MRI and/or BS [15–18]. Table 3 presents an overview of this literature. The wide variation in diagnostic performance of MRI, CT and BS in these different studies is remarkable. The variation in results will be partly due to the use of varying reference standards. Some studies used repeated MRI or CT, while others used repeated radiographs after 2 weeks or after 6 weeks and, like we did in the present study, included the clinical follow-up in the reference standard [13]. Another explanation for the diverse result may be found in different imaging protocols used for CT and MRI. As this study is the first to evaluate CT, MRI and BS in one patient series, it is of additional value to the existing evidence despite some shortcomings.

As in all studies that attempt to determine sensitivity and specificity, a reference standard is mandatory. The chosen reference standard is however a point of debate. Repeated radiographs alone are often being used as the reference standard. However, Low and Raby showed that repeated radiographs have a sensitivity of around 20 % and a specificity of around 85 % with poor interobserver agreement [10]. Other studies showed that repeated radiographs only reveal 2 % additional scaphoid fractures [11–13, 19]. Clinical signs are also shown in the literature to be of poor predictive value when attempting to diagnose a scaphoid fracture [20]. Anatomic Snuff Box tenderness is a sensitive, but non-specific sign [21]. Clinical criteria are unreliable for a diagnosis of acute scaphoid fracture to be made [22]. However, in a more recent study by Duckworth et al., repeated clinical assessment combined with radiographs was also used, with satisfactory results, in order to develop a clinical prediction rule [23]. Moreover, in our study 10 percent of the included patients with a suspected scaphoid fracture had indeed a scaphoid fracture according to the reference standard, which is conform literature [13, 24, 25]. and thus substantiates the use of the chosen reference standard. Given the above, the sole use of repeated radiographs after 6 weeks is not adequate and will still lead to missed scaphoid fractures. The additional value of repeated clinical evaluation is in our opinion crucial.

Since all of the reference standards have limitations and none can be considered 100 % accurate, final solid results are not available. Moreover, due to the low incidence of true scaphoid fractures, small variations are easily magnified [24]. A recent study by Buijze et al. has introduced a statistical method which could potentially encounter this problem using latent class analysis. They suggest to deal with probabilities rather than certainties for optimisation of the diagnosis and treatment of scaphoid fractures. This method is promising, however no prospective study using this method has been published yet [15].

Another potential weakness of the study is the small sample size. There were 33 patients included, and in only three patients an occult scaphoid fracture was revealed. Because of the small sample size the value of the no precise estimation of the diagnostic accuracy of the separate modalities could be given. However, the specific advantages and limitations of the three diagnostic modalities could well be illustrated in our study. According to the literature MRI has the best performance in diagnosing occult scaphoid fractures with reasonable specificity and sensitivity (in this study a 1.5 T MRI scan is used. Modern MRIs may have better diagnostic performance. However there is no literature to support this). Moreover it will also diagnose soft-tissue injuries [26]. A disadvantage of MRI is the time consuming procedure, that is not always readily available and the costs are relatively high. Advantages of CT are its specificity, availability and the costs are relatively low in comparison with MRI and BS. CT is however less sensitive than MRI and BS. Some suggest this is due to the fact that CT does not detect trabecular scaphoid fractures, whereas MRI and BS do [27]. Furthermore a CT scan involves radiation exposure [28]. The main advantage of BS is its sensitivity and some suggest that is why BS is the investigation of choice. On the other hand, BS tends to over-diagnose scaphoid fractures because it provides false positive results in case of bone bruises and other pathology that increases bone turn-over [18, 26]. Another limitation of the BS is that the exact location of the lesion may be difficult to determine [29]. Furthermore BS leads to radiation exposure, is invasive and leads to a delay of 3–5 days. The specific advantages and limitations of each of the diagnostic modalities are summarized in Table 4.

This study illustrates the possibilities and shortcomings of MRI, CT and BS in diagnosing scaphoid fractures in this group of patients. The difficulties that can be encountered when attempting to analyse their diagnostic performance in a reliable way, are demonstrated in the following three patients:

Table 4 Summary of advantages and disadvantages of MRI, CT and BS

MRI	CT	BS
Advantages	*Advantages*	*Advantages*
Specificity	Specificity	Sensitivity
Injury of ligaments	Fast	
	Availability	
Disadvantages	*Disadvantages*	*Disadvantages*
Sensitivity	Sensitivity	Specificity
Availability	Radiation exposure	Radiation exposure
Time consuming		Invasive
		Time consuming
		Delay 3–5 days

Fig. 1 BS showing activity in the scaphoid area. The nuclear physician reviewed this image as a scaphoid fracture

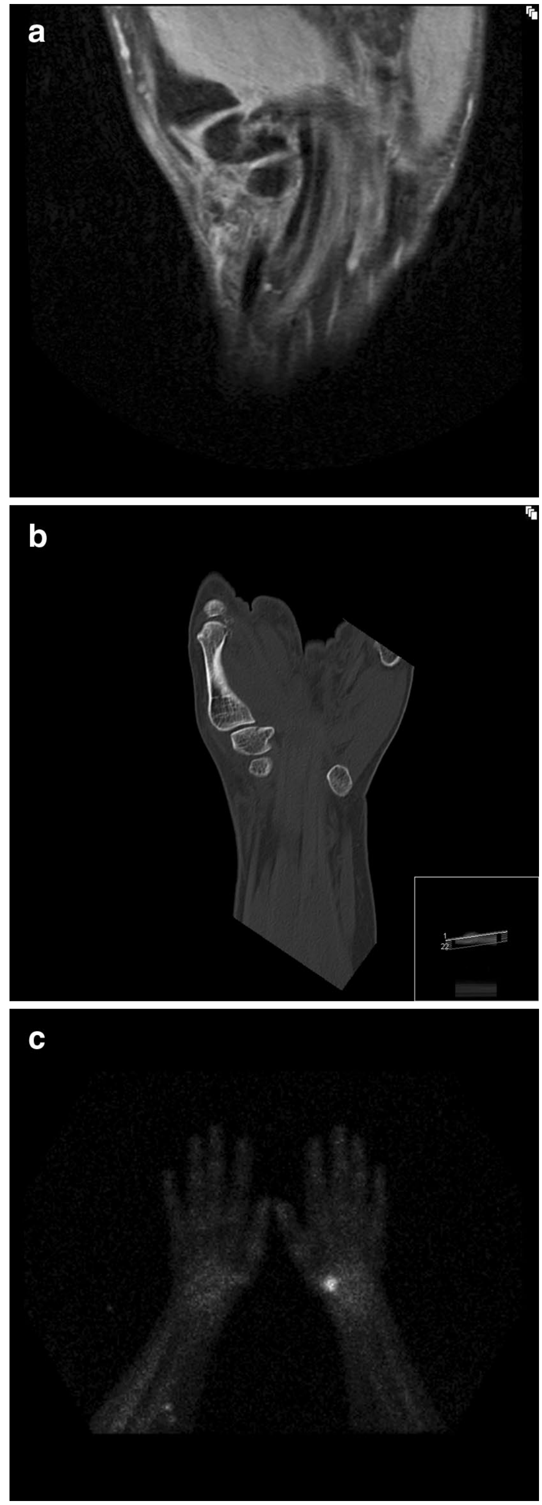

Fig. 2 **a** *T*2 image of a MRI showing a trapezium fracture. **b** Image of a CT showing cortex interruption of the trapezium. **c** BS with activity in the scaphoid area. The nuclear physician reviewed this image as a scaphoid fracture

1. This patient had a negative MRI and CT. The BS was positive for a scaphoid fracture (Fig. 1). At 6 weeks there were clear clinical signs of a fracture with obvious pain in the anatomic snuffbox. The radiograph did however not show a fracture. Combining these data with the fact that MRI and CT may miss scaphoid fractures and BS is highly sensitive but may give false-positive results, this clearly illustrates the lack of a reliable reference standard and the challenge in decision making. Finally, the clinical signs were decisive for the final diagnosis (fracture).
2. In this patient the MRI and CT showed a trapezium fracture (Fig. 2a, b). The diagnosis of the BS was scaphoid fracture (Fig. 2c). This example illustrates that BS does not always adequately indicate the exact localization of the fracture.

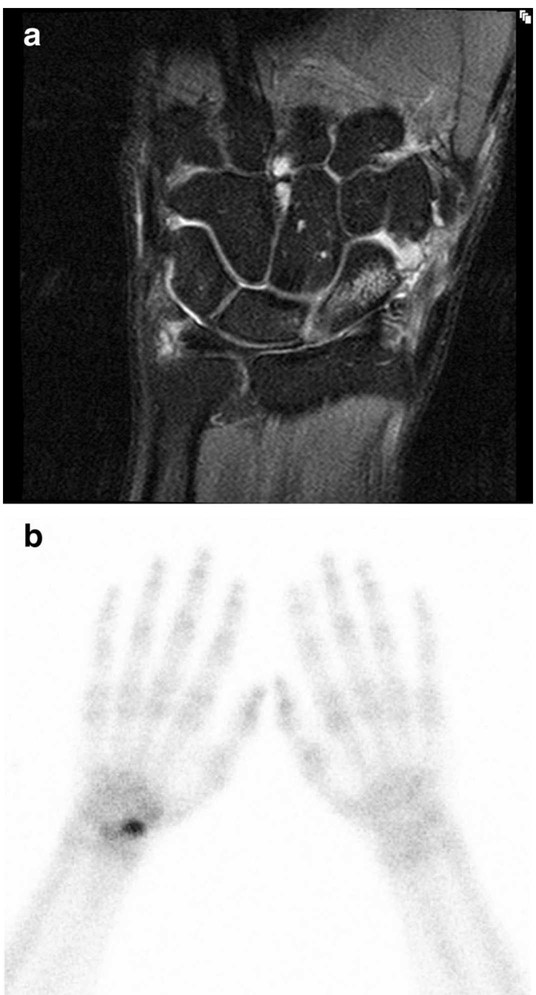

Fig. 3 **a** *T*2 MRI image showing bone oedema and interruption of trabecular bone. The radiologists reviewed this as a trabecular scaphoid fracture. **b** BS showing activity in the scaphoid area, reviewed as a scaphoid fracture

3. In this patient MRI showed a trabecular fracture of the scaphoid (Fig. 3a) and BS was positive for a scaphoid fracture (Fig. 3b), whereas CT showed no fracture. This example illustrates that CT is not adequate in the diagnosis of trabecular fractures.

Despite the common availability of advanced imaging techniques, occult scaphoid fractures remain difficult to diagnose. BS, CT and MRI all have their short comings when used for diagnosing scaphoid fractures. MRI and CT miss fractures and BS tends to over-diagnose. On the other hand, these imaging modalities will account for 10 % additionally diagnosed scaphoid fractures and 25 % other wrist and carpal fractures. Regardless of which diagnostic modality is chosen, it is important that every patient with a suspected scaphoid fracture should be followed with great care and clinical re-evaluation, since neither MRI, nor CT and BS are 100 % accurate in diagnosing occult scaphoid fractures. The specific advantages and limitations of each diagnostic modality should be familiar to the treating physicians and taken into consideration during the diagnostic process.

Compliance with ethical standards

Conflict of interest Andele D. de Zwart, Frank J.P. Beeres, MD, PhD, Steven J. Rhemrev, Kees Bartlema and Inger B. Schipper declare that they have no conflict of interest.

Research involving human participants This study was approved by the Medical Ethics Committee of the Leiden University Medical Center (Protocol Number P06.044).

Informed consent The patients participating in this study provided written informed consent.

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