Martin J. Breitenseher, MD • Viktor M. Metz, MD • Louis A. Gilula, MD • Christian Gaebler, MD
Christian Kukla, MD • Dominik Fleischmann, MD • Herwig Imhof, MD • Siegfried Trattnig, MD

Radiographically Occult Scaphoid Fractures: Value of MR Imaging in Detection[1]

PURPOSE: **To evaluate the diagnostic value of magnetic resonance (MR) imaging in patients with clinical suspicion of scaphoid fractures and normal initial plain radiographs.**

MATERIALS AND METHODS: **MR imaging was performed within 7 days after trauma in 42 patients with clinical suspicion of scaphoid fractures and normal plain radiographs. T1-weighted spin-echo, T2*-weighted gradient-echo, and short inversion time inversion-recovery (STIR) sequences were performed. MR images were evaluated independently by two radiologists. Six-week follow-up radiographs were used as a standard to diagnose fractures.**

RESULTS: **MR imaging depicted occult fractures of the scaphoid bone in 14 patients (33%), the capitate bone in four (10%), the trapezium in one (2%), and the distal radius in two (5%). All wrist fractures were detected with a combination of STIR and T1-weighted spin-echo sequences. The sensitivity and specificity for detection of radiographically occult fractures of the wrist were 100% each for the first and 95% and 100%, respectively, for the second radiologist with an almost perfect interobserver agreement (κ = 0.953).**

CONCLUSION: **MR imaging has a high sensitivity for detection of fractures of the scaphoid bone and wrist not evident on plain radiographs and may enable early diagnosis and treatment.**

The scaphoid is one of the most commonly fractured bones of the wrist (1,2). Scaphoid fractures occur most often in young adults (age range, 15–40 years) (3) and have been reported to have a high rate of complications. These complications include delayed union, nonunion, or avascular necrosis, especially if diagnosis is delayed (4–6). In addition, the rate of radiographically occult scaphoid fractures is high (7).

However, it is also well recognized that additional radiographic views have been designed and advocated to better depict scaphoid fractures on plain radiographs (8–13), and two of these views necessitate the use of special positioning devices (10,13). In many cases, however, the diagnosis of scaphoid fracture is delayed until 2 weeks after trauma, when follow-up radiographs of the scaphoid demonstrate the "initially occult" scaphoid fracture because of resorption and better demarcation around the fracture line (14). If these radiographs are still negative and a high clinical suspicion of scaphoid fracture persists, the wrist must be immobilized for a longer period. If no fracture is visible on radiographs at 6 weeks after trauma, it is probably safe to discontinue immobilization (14).

Radionuclide bone scanning has been considered the imaging technique of choice for early diagnosis of occult fractures (15,16). Although positive bone scan findings may be sufficient for diagnosis, the lack of spatial resolution on bone scans necessitates further imaging studies such as conventional tomography, computed tomography (CT), or magnetic resonance (MR) imaging for more precise anatomic information before definitive treatment.

MR imaging has been reported to be valuable in diagnosis of complications of scaphoid fractures such as delayed union, nonunion, or avascular necrosis (17–22). However, the value of early performance of MR imaging in patients with suspicion of occult scaphoid fractures has not been reported, to our knowledge. The purpose of our study was to evaluate the diagnostic potential of MR imaging in patients with clinical suspicion of scaphoid fractures and initial normal plain radiographs.

MATERIALS AND METHODS

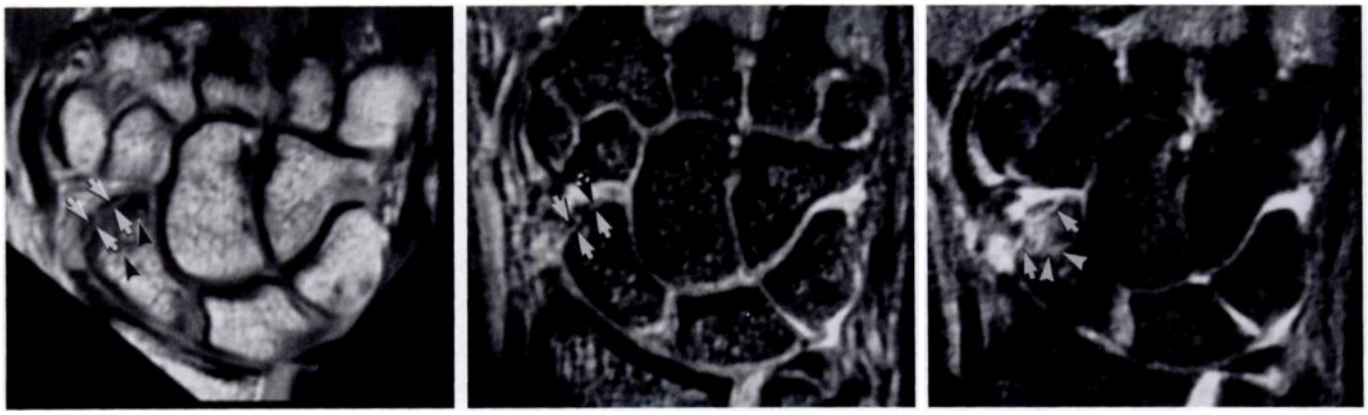
The prospective study included 42 consecutive patients (23 male, 19 female; age range, 10–66 years; mean, 30.5 years ± 13.8 [standard deviation]) who presented to our clinic for trauma surgery between January 1995 and March 1996 with clinical suspicion of scaphoid fracture after acute wrist injury. In these patients, two initial and four subsequent plain radiographs of the wrist failed to demonstrate a fracture. The clinical criteria for scaphoid fracture

Index terms: Magnetic resonance (MR), comparative studies, 43.11, 43.121411, 43.121412, 43.121413 • Wrist, fractures, 43.41 • Wrist, MR, 43.1214, 43.121412, 43.121413

Abbreviation: STIR = short inversion time inversion recovery.

Radiology 1997; 203:245–250

[1] From the MRI Institute, Department of Radiology, and Ludwig Boltzmann Institute of Radiological Tumor Research (M.J.B., V.M.M., D.F., H.I., S.T.) and the Clinic for Trauma Surgery (C.G., C.K.), University of Vienna, Allgemeines Krankenhaus, Waehringer Guertel 18–20, A-1090 Vienna, Austria; and Mallinckrodt Institute of Radiology, Washington University Medical School, St Louis, Mo (L.A.G.).
Received July 12, 1996; revision requested August 22; revision received November 6; accepted November 11. **Address reprint requests to** M.J.B.



a. b. c.

Figure 1. Radiographically occult fracture of the distal pole of the scaphoid bone in a 23-year-old man. Images were obtained 6 days after trauma. **(a)** Coronal T1-weighted (500/20) image of the scaphoid shows a hyperintense fracture line near the distal pole of the scaphoid (between arrows), with decreased signal intensity of the surrounding bone marrow (arrowheads). **(b)** Corresponding coronal T2*-weighted gradient-echo (60/17, 20° flip angle) image shows the fracture line (between arrows), but the change in signal intensity in the bone marrow is not seen, underscoring the low value of this sequence in this area. **(c)** Coronal fast STIR image (1,200/13/130) clearly shows the high signal intensity of the cortical and trabecular fracture line (arrows) and intermediate signal intensity of the bone marrow abnormality (arrowheads).

were pain, swelling, and tenderness at the anatomic snuff-box.

The two initial plain radiographs were focused on the wrist, including the distal radius but not the hand in anteroposterior and lateral projections and were obtained first as screening views. If the initial radiographs were negative for fracture, four additional radiographs were obtained of the wrist in the posteroanterior projection (with the wrist in ulnar deviation), the lateral projection, and two oblique projections within 5 days after trauma. These radiographs were evaluated for radiographic signs of a scaphoid or other wrist bone fracture such as a sharp, radiolucent line within the intraosseous trabecular pattern, a distinct break in continuity of the cortex, or a distinct sharp step-off of the cortex of the scaphoid or other wrist bone. If radiographs were negative but there was clinical suspicion of a scaphoid fracture, it was diagnosed as a possible occult scaphoid fracture. Patients with initial radiographic evidence of a wrist fracture were excluded from the study.

MR imaging was performed in all patients within 7 days after trauma (mean, 3.8 days) with a 1.0-T unit (Gyroscan T10-NT; Philips, Best, The Netherlands) and a circular surface coil (C3; Philips; 14 cm [external diameter], 11 cm [internal diameter]). In all cases, three sequences were performed. The first sequence was coronal T1-weighted spin-echo (repetition time, 500 msec; echo time, 20 msec [500/20]), and the second sequence was coronal fast short inversion time inversion-recovery (STIR) (1,200/13/130 [inversion time]). For both sequences, a section thickness of 2.4 mm with an intersection gap of 0.3 mm and four signals acquired were used. The third sequence was coronal T2*-weighted three-dimensional gradient-echo (60/17; flip angle, 20°) with an effective section thickness of 1.5 mm and one signal acquired. A 14-cm field of view and a 256 × 256 matrix were applied in all three sequences.

A diagnosis of wrist fracture was considered to be made at MR imaging if there was evidence of a cortical fracture line, a trabecular fracture line, a bone marrow abnormality that involved a diffuse area of a wrist bone (23–25), or the combination of two or three of these signs. We evaluated the signal intensity of the fracture lines and bone marrow abnormality patterns as low, equal (invisible), or high compared with that of the adjacent osseous structures on MR images obtained with the three sequences (T1-weighted spin-echo, STIR, and T2*-weighted gradient-echo). The main location (distal, middle, proximal third) and orientation (horizontal, oblique, vertical) of the fracture line were described.

Follow-up radiographs of the wrist were obtained in the same four views 2 (10–14 days), 4, and 6 weeks after trauma in all patients. The diagnosis of an occult scaphoid fracture, as well as the other detected wrist fractures, was based on the presence of a sclerotic line and/or resorption around the fracture line on radiographs obtained after 6 weeks compared with initial radiographs in all cases.

The initial radiographs were evaluated by a trauma surgeon. The MR images were analyzed independently and prospectively by two experienced radiologists (M.J.B., S.T.). The observers assessed the MR images without knowledge of the follow-up radiographic findings. Radiographs obtained 2, 4, and 6 weeks after trauma were evaluated in a blinded fashion by two different investigators who did not participate in the previous readings and did not have knowledge of MR imaging findings. The results from the 6-week follow-up radiographs (fracture or no fracture) were compared with those from MR imaging (fracture or no fracture).

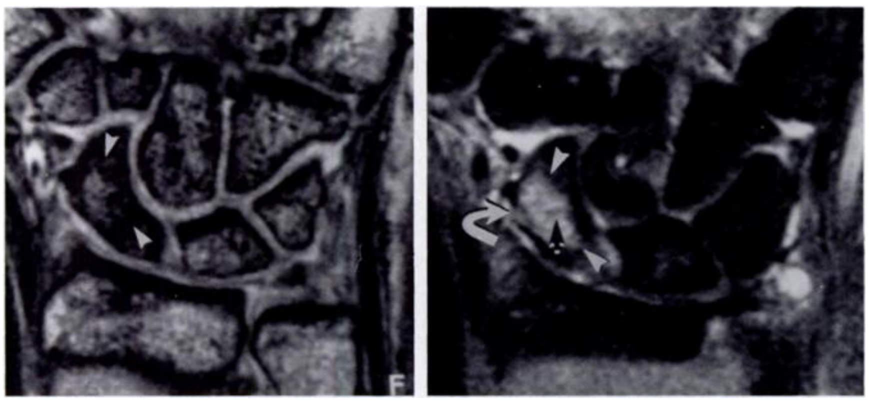
By using the 6-week follow-up radiographs as a standard (8,12,14,26–29), sensitivity, specificity, and accuracy were calculated. Interobserver agreement was expressed in terms of the κ statistic (30) as a two-level κ result, with MR images interpreted as positive or negative. Interobserver agreement was defined as almost perfect ($\kappa > 0.80$), good ($\kappa = 0.80$–0.61), moderate ($\kappa = 0.60$–0.41), fair ($\kappa = 0.40$–0.21), and poor ($\kappa \leq 0.20$) (30).

RESULTS

In 20 patients (48%) in whom initial radiographs (obtained 5 days or less after trauma) were negative, fractures of the wrist bones could be detected with MR imaging. The fracture was located in the scaphoid bone in 14 (33%) of 42 patients, in the capitate bone in four (10%) patients, in the trapezium in one (2%) patient, and in the distal radius in two (5%) patients. In the patient with a fracture of the trapezium, a fracture of the scaphoid bone was also present. Therefore, a total of 21 fractures of wrist bones in 20 patients demonstrated at MR imaging were not seen on the initial plain radiographs (Figs 1–3).

In these wrist fractures, a combination of a trabecular fracture line and perifocal bone marrow abnormality was visible in 13 (62%) cases. Ten of these 13 cases demonstrated a cortical fracture line. In four (19%) cases, there was only a trabecular fracture line without perifocal bone marrow abnormality. In two of these four cases, an associated cortical fracture line was present. In four (19%) cases, diffuse bone marrow abnormality without a trabecular fracture line was present. In two of the latter cases, a cortical fracture line in addition to diffuse bone marrow abnormality but without evidence of a trabecular fracture line was found. Thus, in two cases, diffuse bone marrow abnormality was the only finding according to the previously mentioned definition of wrist trauma.

a. b. c.



d. e.

Figure 2. Radiographically occult midthird scaphoid fracture in an 18-year-old man. **(a)** Initial radiograph of the scaphoid shows no fracture. **(b)** Radiograph of the scaphoid obtained at 6-week follow-up shows a midthird scaphoid fracture (arrows). **(c)** Coronal T1-weighted (500/20) image of the scaphoid obtained 3 days after trauma shows a hypointense trabecular fracture line in the mid- and proximal thirds of the scaphoid (arrows) with adjacent bone marrow abnormality (arrowheads). **(d)** Coronal T2*-weighted gradient-echo (60/17, 20° flip angle) image demonstrates minimal increased signal intensity at this region, indicating bone marrow abnormality (arrowheads). The fracture line is not clearly depicted. **(e)** Coronal fast STIR image (1,200/13/130) shows highly increased signal intensity of bone marrow abnormality (arrowheads). The trabecular fracture line (straight arrow) is less visible than in **c**; however, involvement of the cortex is clearly demonstrated (curved arrow).

A diagnosis of wrist fracture was considered to be made at MR imaging if there was evidence of a cortical fracture line, a trabecular fracture line, a bone marrow abnormality, or the combination of two or three of these anomalies. On the 6-week follow-up radiographs, a diagnosis of fracture with MR imaging was confirmed in all cases. Even the two cases of traumatic diffuse bone marrow abnormality were confirmed as fractures on the 6-week follow-up radiographs. All other patients with initial clinical signs of scaphoid fracture, in whom radiographs were interpreted as normal at 6-week follow-up, were completely without any bone abnormality at MR imaging (n = 22).

The sensitivity and specificity for primary detection of radiographically occult fractures with MR imaging were 100% each for the first reader and 95% and 100%, respectively, for the second reader with the 6-week follow-up radiographs used as the standard. With MR images interpreted as positive or negative, the interobserver agreement was almost perfect ($\kappa = 0.953$) for MR imaging and perfect for 6-week radiographs. In one patient, the second reader reported a false-negative diagnosis with MR imaging. This false-negative diagnosis resulted from negative interpretation of MR images of an incomplete fracture without bone marrow abnormality but a positive radiograph after 6 weeks.

On the T1-weighted images, trabecular fracture lines were hypointense in 13 cases and hyperintense in two cases (Table 1). On images obtained with the STIR sequence, a trabecular fracture line was seen in 15 fractures; four were hypointense and 11 were hyperintense. Two trabecular fracture lines that were of equal signal intensity (invisible) to that of the surrounding bone marrow abnormality on the T1-weighted spin-echo image could be detected with the STIR sequence. In two cases, fracture lines were of equal signal intensity (invisible) on images obtained with the STIR sequence and of low signal intensity on T1-weighted spin-echo images. With the T2*-weighted gradient-echo sequence, eight trabecular fracture lines were seen: six of low signal intensity and two of high signal intensity. No additional trabecular fracture line was found by using this sequence.

A cortical fracture line was seen with the T1-weighted spin-echo sequence in three cases, with the STIR sequence in 14 cases, and with the T2*-weighted gradient-echo sequence in two cases (Table 1). Bone marrow abnormality was seen with the T1-weighted spin-echo sequences in 17 cases as low signal intensity relative to that of normal bone marrow, with the STIR sequence in 17 cases as high signal intensity relative to that of normal bone marrow, and with the T2*-weighted gradient-echo sequence in 10 cases, in eight of these cases as high signal intensity and in two cases as low signal intensity relative to that of normal bone marrow (Table 1).

For the first reader, the sensitivity of MR imaging in detection of occult fracture by using the presence of a trabecular fracture line visible at MR imaging as a positive sign was 88% for the T1-weighted spin-echo sequence, 88% for the STIR sequence, and 47% for the T2*-weighted gradient-echo sequence. The sensitivities for detection of a cortical fracture line were 21%, 100%, and 14% (T1-weighted spin-echo, STIR, and T2*-weighted gradient-echo sequences, respectively), and the sensitivities for detection of a bone marrow abnormality were 100%, 100%, and 59%, respectively. The combination of the T1-weighted spin-echo and STIR sequences had the highest sensitivity for demonstration of a trabecular or cortical fracture line.


a. b. c.

Figure 3. Radiographically occult midthird, horizontal capitate fracture in a 24-year-old woman. Images were obtained 4 days after trauma. **(a)** Coronal T1-weighted (500/20) image of the wrist shows a hypointense trabecular fracture line (arrows) with a minimally hypointense surrounding bone marrow abnormality (arrowheads). **(b)** Coronal T2*-weighted gradient-echo (60/17, 20° flip angle) image shows a hyperintense fracture line (arrows) and hypointense bone marrow diffusely throughout the capitate bone. **(c)** Coronal fast STIR image (1,200/13/130) shows a hyperintense trabecular fracture line (straight arrows), hyperintense bone marrow (arrowheads), and involvement of the cortex with a clear hyperintense cortical fracture line (curved arrow).

Table 1
MR Imaging Findings in 21 Wrist Fractures with Three Sequences

	Trabecular Fracture Line (n = 17)			Cortical Fracture Line (n = 14)			Bone Marrow Edema (n = 17)		
MR Imaging Findings	T1-weighted Spin-Echo	STIR	T2*-weighted Gradient-Echo	T1-weighted Spin-Echo	STIR	T2*-weighted Gradient-Echo	T1-weighted Spin-Echo	STIR	T2*-weighted Gradient-Echo
Low signal intensity	13	4	6	0	0	0	17	0	2
Equal signal intensity*	2	2	9	11	0	12	0	0	7
High signal intensity	2	11	2	3	14	2	0	17	8
Sensitivity (%)	88	88	47	21	100	14	100	100	59

* Invisible fracture on MR images.

Among the 14 scaphoid fractures, the fracture was located in the distal third of the bone in six cases (avulsion fracture), in the middle third in seven cases, and in the proximal third in one case. The fractures were horizontal in four cases, oblique in eight, and vertical in two. The four capitate fractures were transverse and were located in the middle third. The trapezium fracture was located in the middle third and was horizontal. The two distal radius fractures were horizontal and extraarticular.

The time between trauma and MR imaging in the group with fractures (n = 21) was from 1 day (minimum, 25 hours) to 6 days (mean, 3.7 days) and in the group without fractures (n = 22), 1 day (minimum, 21 hours) to 7 days (mean, 3.9 days). Radiographs obtained 2 weeks after trauma demonstrated 11 (52%) of 21 fractures or an accuracy of 79% for demonstration of wrist fractures compared with 100% on 6-week follow-up radiographs (Table 2). Therefore, radiography was not reasonably accurate and could not represent an alternative to MR imaging because of the time difference, which was 3.7 days for MR imaging and 21.8 days for follow-up radiography; this difference represented an average time saved of 18.1 days with use of MR imaging.

DISCUSSION

Our results demonstrate the superior diagnostic value of MR imaging in patients with clinically suspected scaphoid fracture but negative radiographs. Early diagnosis of scaphoid fracture was obtained in all patients with MR imaging compared with follow-up radiography owing to the advantage of increased detailed anatomic information with MR imaging. Correct diagnosis with MR imaging provided the benefit of initiation of early definitive treatment with 6-week immobilization for a wrist fracture. One of the advantages of MR imaging is to show fracture lines more clearly than plain radiography (31).

MR imaging is exquisitely sensitive to bone marrow abnormalities and therefore renders even nondisplaced fractures as obvious (23,32). These findings are present immediately after trauma. As precise anatomic information is an advantage associated with MR imaging, further investigations are not necessary. Seven unsuspected fractures of the wrist other than fractures of the scaphoid bone were also detected with high accuracy by using MR imaging.

MR imaging has demonstrated diagnostic usefulness in radiographically occult fractures in large bones such as the proximal femur (23,32,33). Associated bone marrow abnormalities adjacent to fractures were detected in most instances, which demonstrated the specificity of MR imaging (33). The advantage of early detection of an occult fracture of the proximal femur decreased the chance that a simple nondisplaced fracture would displace and require more complex management. Early diagnosis and treatment results of femoral fractures can potentially lead to a decreased hospital stay, reduced morbidity, and therefore decreased costs (32,33). In addition to occult complete fractures

Table 2
Accuracy and Sensitivity of Radiographs Obtained at Different Times after Trauma

Radiographic Findings	Interval			
	Initial	2 wk	4 wk	6 wk
Normal	42	31	26	22
Fractures	0	11	17	21
Accuracy (%)	52	79	91	100
Sensitivity (%)	0	55	81	100

that breach the cortex, several types of subtle or radiographically occult fractures can be diagnosed definitively with MR imaging. Those include osteochondral fractures, stress fractures, and occult intraosseous fractures or various causes of bone marrow abnormality (24,25,34).

In the proximal femur, an exact diagnosis of occult fractures was possible if MR images were limited to T1-weighted sections (33). Other MR imaging sequences, such as fat-suppressed, STIR, or T2-weighted, were also performed, but they were considered optional (35). In our study, STIR and T1-weighted spin-echo sequences demonstrated fracture lines of the bone marrow and bone marrow edema with an equal frequency, although in the cases of bone marrow edema, a fracture line was seen in two cases on T1-weighted spin-echo images only and in two other cases on STIR images only. The STIR sequence was found to be superior in the evaluation of a cortical fracture line. T2*-weighted gradient-echo imaging was inferior in the evaluation of a trabecular or cortical fracture line and in the evaluation of bone marrow edema.

Although plain radiography, especially the use of radiographically detailed views (8–13), is the examination of first choice in all suspected wrist fractures, difficulties are encountered if radiographs are normal, particularly if a strong clinical suspicion of scaphoid fracture is present. Despite the fact that radiography may fail to demonstrate scaphoid fractures, this modality is still used first (12,14). A high percentage of clinically suspected fractures of the scaphoid bone cannot be confirmed at radiographic examination (36). In some studies, from 25% (3,37) to 65% (7) of scaphoid fractures were missed at radiographic examination. In our study, 33% of patients had occult scaphoid fractures, which were found with MR imaging and follow-up radiography. Radiography is not a reliable aid in diagnosis or exclusion of all scaphoid fractures, irrespective of the training and experience of the observer (7). Radiography was repeated after 10–14 days and finally after 6 weeks in those patients with persistent clinical symptoms without original radiographic evidence of fracture. If no fracture is seen on radiographs after 6 weeks, it is probably safe to discontinue immobilization (14).

Plain radiography is the first step and may help diagnose scaphoid fracture. If early diagnosis is necessary, negative radiographs and clinical suspicion of a scaphoid fracture necessitate further investigation with other detailed views, bone scanning, or MR imaging.

Until now, radionuclide bone scanning has gained acceptance as a method for early detection of occult fractures (15,16,38). Previous studies have shown that bone scanning provides a sensitivity up to 100%, a specificity of 98%, a positive predictive value of 93% (16), and high intra- and interobserver agreement (15) in the detection of occult fractures of the scaphoid, making it a sensitive and accurate examination. Bone scans can demonstrate increased tracer uptake in an area of osseous injury, but the same findings might be seen in disuse states, ligament injuries, or reflex sympathetic dystrophy (35,39). Although positive bone scan findings may be sufficient for diagnosis, the associated lack of spatial resolution necessitates further imaging studies such as conventional tomography, CT, or MR imaging for more precise anatomic information before definitive treatment. A period of 2–3 days may be necessary to demonstrate a fracture on bone scans (40). Rizzo et al (35), who identified hip fractures in 62 patients with normal plain radiographs, found that MR imaging performed within 24 hours of radiography was as sensitive as bone scanning within 72 hours. In cases of occult fracture, MR imaging has the advantage of not only depicting the fracture, but also aiding assessment of extent and location.

CT seems to be less sensitive in demonstration of all scaphoid fractures. In one study (41) in which CT scans were obtained 6 weeks after trauma, 18 of 21 fractures were identified, and the diagnosis was missed at CT in three patients with proved fractures on follow-up plain radiographs at 6 weeks. Conversely, CT has been reported as more accurate in the evaluation of occult wrist fractures in another study (42). That study reported 16 patients with persistent wrist pain after trauma in whom CT demonstrated 21 wrist fractures in all of the patients. In the latter study, there was a range of 11 days to 4 years between trauma and CT, whereas in the other study there was an interval of 6 weeks after trauma.

To our knowledge, there is no available study with regard to the value of initial CT in occult wrist fractures. CT has been demonstrated to be more sensitive compared with radiography when performed as a dedicated examination 6 weeks after trauma (41,42). No data are available, however, on the sensitivity of CT performed initially after trauma. Although CT might have a high sensitivity for occult wrist fractures, MR imaging seems to be superior as an initial examination because it enables visualization of bone marrow abnormality in nondisplaced fractures.

MR imaging should be applied in cases of wrist trauma where an occult scaphoid fracture is suspected clinically but radiographs are negative, if appropriate clinical guidelines are followed to achieve a high detection rate and to be cost-effective. These clinical guidelines include a history of sustained wrist injury (primarily a fall on the outstretched, dorsiflexed hand), pain and swelling at the anatomic snuff-box, and restriction of wrist movement. An examination with one finger to detect tenderness over the scaphoid tuberosity compared with that of the other wrist or tenderness from pushing the thumb proximally is also valuable. All of these are clinical guidelines for the efficient use of MR imaging in detection of occult fractures (29,43,44).

MR imaging can be cost-effective in the setting of acute trauma, suspected fracture, and normal radiographs of the wrist, as MR imaging reduces the interval from manifestation of symptoms to definite diagnosis. Early MR imaging obviates other examinations such as bone scanning or short-term follow-up radiography for diagnostic reasons and therefore makes the diagnosis a simple one-step procedure. Thus, definitive treatment is initiated earlier. Patients with wrist sprains in whom the diagnosis is supported by normal MR imaging findings return to productivity earlier. This earlier return to function represents the main component of cost-effectiveness.

A precise measure of cost-effectiveness is difficult to calculate, since factors such as the cost of the examination, as well as sensitivity and specificity of the test, must be included. Also, the prevalence of the disease in the population under investigation is an important issue (45). Despite the lack of precise figures that pertain to costs of a lost working day and follow-up examination, the following general calculation, which is based on our data and assumes a strategy that includes radiography and MR imaging, leads to the following scenario.

Our study indicates that in patients with a fracture, MR imaging costs are additional costs. This group of patients produces follow-up costs similar to those of patients with a fracture who did not undergo MR imaging, since follow-up radiographs and clinical follow-up examinations are necessary to document fracture healing because the same therapy is used. Therefore, MR imaging was an additional cost in the fracture group. In the group without fractures, however, follow-up radiographs were unnecessary. In 22 patients, 27 follow-up radiographs were obtained (four scaphoid views) and 27 clinical follow-up examinations were performed. Of 22 patients, 20 had a simple wrist sprain and two had ligamentous lesions. In the wrist sprain group with clinically suspected scaphoid fracture, fixation was performed within 10 days to 6 weeks (mean, 13.4 days). If a fracture is excluded at MR imaging and a wrist sprain is diagnosed, fixation is not necessary. In summary, cost-effectiveness can be estimated by means of a simple plus-minus determination, such as +42 MR imaging studies, −27 follow-up radiographic studies, up to −27 clinical follow-up examinations, −268 days fixation (mean, 13.4 days), and up to −238 workdays (mean, 11.9 days).

In cases of clinically suspected, radiographically occult scaphoid fracture, MR imaging offers a high sensitivity as the second diagnostic procedure in detection of radiographically occult fractures of the scaphoid and other wrist bones. MR imaging enables early diagnosis and initiation of early treatment of occult fractures, as well as prevention of overtreatment (several weeks of unnecessary immobilization) in patients without a fracture. The best diagnostic strategy in the management of clinically suspected scaphoid fractures consists of initial radiography followed by MR imaging rather than repeat radiography in patients with negative initial radiographs. ■

References

1. Larsen CF, Brondum V, Skov O. Epidemiology of scaphoid fractures in Odense, Denmark. Acta Orthop Scand 1992; 63:216–218.
2. Resnick D, Goergen TG. Physical injury: extraspinal sites. In: Resnick D, ed. Diagnosis of bone and joint disorders. 3rd ed. Philadelphia, Pa: Saunders, 1995; 2693–2824.
3. Brøndum V, Larsen CF, Skov O. Fracture of the carpal scaphoid: frequency and distribution in a well-defined population. Eur J Radiol 1992; 15:118–122.
4. Stewart MJ. Fractures of the carpal navicular (scaphoid): a report of 436 cases. J Bone Joint Surg [Am] 1954; 36:998–1006.
5. Soutchcott R, Rosman MA. Non-union of carpal scaphoid fractures in children. J Bone Joint Surg [Br] 1977; 59:20–23.
6. Verdan C, Narakos A. Fractures and pseudoarthrosis of the scaphoid. Surg Clin North Am 1986; 48:1083–1095.
7. Tiel-Van Buul MM, Van Beek EJ, Broekhuizen AH, Nooitgedacht EA, Davids PH, Bakker AJ. Diagnosing scaphoid fractures: radiographs cannot be used as a gold standard! Injury 1992; 23:77–79.
8. Russe O. Fracture of the carpal navicular diagnosis, non-operative treatment, and operative treatment. J Bone Joint Surg [Am] 1960; 42:759–768.
9. Gilula LA. Carpal injuries: analysis and exercises. AJR 1979; 133:503–517.
10. Gilula LA, Destouet JM, Weeks PM, et al. Roentgenographic diagnosis of the painful wrist. Clin Orthop 1984; 187:52–63.
11. Conway WF, Destouet JM, Gilula LA, Bellinghausen HW, Weeks PM. The carpal bones: an overview of radiographic evaluation. Radiology 1985; 156:29–31.
12. Dias JJ, Thompson J, Barton NJ, Gregg PJ. Suspected scaphoid fractures. J Bone Joint Surg [Br] 1990; 72:98–101.
13. Yin Y, Mann FA, Gilula LA. Projections and techniques. In: Gilula LA, Yin Y, eds. Imaging of the wrist and hand. Philadelphia, Pa: Saunders, 1996; 93–158.
14. Young MR, Lowry JH, McLeod NW, Crone RS. Clinical carpal scaphoid injuries. Br Med J 1988; 296:825–826.
15. Tiel-Van Buul MM, Van Beek EJ, Van Dongen A, Van Royen EA. The reliability of the 3-phase bone scan in suspected scaphoid fracture: an inter- and intraobserver variability analysis. Eur J Nucl Med 1992; 19:848–852.
16. Tiel-Van Buul MN, Van Beek EJ, Born JJ, Gubler FN, Broekhuizen AH, Van Royen EA. The value of radiographs and bone scintigraphy in suspected scaphoid fracture: a statistical analysis. J Hand Surg [Br] 1993; 18:403–406.
17. Reinus WR, Conway WF, Totty WG, et al. Carpal avascular necrosis: MR imaging. Radiology 1986; 160:689–693.
18. Mitchell DG. Using MR imaging to probe the pathophysiology of osteonecrosis. Radiology 1989; 171:25–26.
19. Cristiani G, Cerofolini E, Squarzina PB, et al. Evaluation of ischemic necrosis of carpal bones by magnetic resonance imaging. J Hand Surg [Br] 1990; 15:249–255.
20. Desser ST, McCarthy S, Trumble T. Scaphoid fractures and Kienböck's disease of the lunate: MR imaging with histopathologic correlation. Magn Reson Imaging 1990; 8:357–361.
21. Imaeda T, Nakamura R, Miura T, Makino N. Magnetic resonance imaging in scaphoid fractures. J Hand Surg [Br] 1992; 17:20–27.
22. DeMouy EH, Edmunds JO Jr, Kronemer KA, Rodriguez RJ, Brown TD. Gadolinium enhancement patterns in carpal navicular fractures: normal and abnormal healing (avascular necrosis, malunion, and nonunion) (abstr). Radiology 1994; 193(P):406.
23. Deutsch AL, Mink JH, Waxman AD. Occult fractures of the proximal femur: MR imaging. Radiology 1989; 170:113–116.
24. Yao L, Lee JK. Occult intraosseous fracture: detection with MR imaging. Radiology 1988; 167:749–751.
25. Kaplan PA, Walker CW, Kilcoyne RF, Brown DE, Tusek D, Dussault RG. Occult fracture patterns of the knee associated with anterior cruciate ligament tears: assessment with MR imaging. Radiology 1992; 183:835–838.
26. Bohler L, Trojan E, Jahna H. Behandlungsergebnisse von 734 frischen einfachen brüchen des kahnbeinkörpers der hand. Reconstr Surg Traumatol 1954; 2:86–111.
27. Trojan E, ed. Der kahnbeinbruch der hand. Vienna, Austria: Hollinek, 1961; 1–122.
28. Abdel-Salam A, Eyres KS, Cleary J. Detecting fractures of the scaphoid: the value of comparative x-rays of the uninjured wrist. J Hand Surg [Br] 1992; 17:28–32.
29. Waizenegger M, Barton NJ, Davis TR, Wartie ML. Clinical signs in scaphoid fractures. J Hand Surg [Br] 1994; 19:743–747.
30. Davies M, Fleiss JL. Measuring agreement for multinomial data. Biometrics 1982; 38:1047–1051.
31. Lang P, Genant HK, Jergesen HE, Murray WR. Imaging of the hip joint: computed tomography versus magnetic resonance imaging. Clin Orthop 1992; 274:135–153.
32. Quinn SF, McCarthy JL. Prospective evaluation of patients with suspected hip fracture and indeterminate radiographs: use of T1-weighted MR images. Radiology 1993; 187: 469–471.
33. Haramati N, Staron RB, Barax C, Feldman F. Magnetic resonance imaging of occult fractures of the proximal femur. Skeletal Radiol 1994; 23:19–22.
34. Mink JH, Deutsch AL. Occult cartilage and bone injuries of the knee: detection, classification, and assessment with MR imaging. Radiology 1989; 170:823–829.
35. Rizzo PF, Gould ES, Lyden JP, Asnis SE. Diagnosis of occult fractures about the hip: magnetic resonance imaging compared with bone-scanning. J Bone Joint Surg [Am] 1993; 75:395–401.
36. Mazet R, Hohl M. Fractures of the carpal navicular: analysis of ninety-one cases and review of the literature. J Bone Joint Surg [Am] 1963; 45:82–122.
37. DaCruz DJ, Bodiwala GG, Finlay DB. The suspected fracture of the scaphoid: a rational approach to diagnosis. Injury 1988; 19:149–152.
38. Hodler LE, Schwarz C, Wernicke PG, Michael RH. Radionuclide bone imaging in the early detection of fractures of the proximal femur (hip): multifactorial analysis. Radiology 1990; 174:509–515.
39. Pin PG, Semenkovich JW, Young VL, et al. Role of radionuclide imaging in the evaluation of wrist pain. J Hand Surg [Am] 1988; 13:810–814.
40. Matin P. The appearance of bone scans following fractures, including immediate and long term studies. J Nucl Med 1979; 20:1227–1231.
41. Tiel-Van Buul MM, Van Beek EJ, Dijkstra PF, Bakker AD, Broekhuizen TH, Van Royen EA. Significance of a hot spot on the bone scan after carpal injury: evaluation by computed tomography. Eur J Nucl Med 1993; 20:159–164.
42. Hindman BW, Kulik WJ, Lee G, Avolio RE. Occult fractures of the carpals and metacarpals: demonstration by CT. AJR 1989; 153:529–532.
43. Chen SC. The scaphoid compression test. J Hand Surg [Br] 1989; 14:323–325.
44. Barton NJ. Twenty questions about scaphoid fractures. J Hand Surg [Br] 1992; 17:289–310.
45. Hunink MG. Outcomes research and cost-effectiveness analysis in radiology. Eur Radiol 1996; 6:615–620.