Skeletal Radiology (2019) 48:103–108
https://doi.org/10.1007/s00256-018-3004-7

SCIENTIFIC ARTICLE

Diagnostic accuracy of an abbreviated MRI protocol for detecting radiographically occult hip and pelvis fractures in the elderly

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Received: 24 January 2018 / Revised: 23 April 2018 / Accepted: 5 June 2018 / Published online: 18 June 2018

Abstract

Objective To determine the diagnostic accuracy of an abbreviated, two-sequence MRI protocol using limited pulse sequences for the detection of radiographically occult hip and pelvis fractures in the elderly compared to the complete MRI examination.

Materials and methods One hundred and eleven consecutive emergency department patients age 65 or older who had undergone MRI to evaluate for clinically suspected hip fracture after negative radiographs were included in the study. The large field-of-view coronal T1 and STIR sequences were isolated from the complete six-sequence MRI protocol and reviewed independently in a blinded fashion by two musculoskeletal fellowship-trained radiologists who recorded presence or absence of fractures of the proximal femora or pelvis, fracture type, and presence or absence of soft tissue injury. Test accuracy was calculated with 95% confidence intervals and accuracy of fracture classification for the abbreviated protocol was compared to that made on the basis of the full exam.

Results For proximal femoral fractures, the abbreviated protocol had a pooled sensitivity and specificity for the two readers of 100 and 97%, respectively. For pelvic fractures, sensitivity was 92% and specificity was 98%. The kappa coefficient for fracture classification was 0.90 for reader 1 and 0.88 for reader 2, indicating excellent agreement for both readers in fracture classification compared to the classification made based on the complete MRI protocol.

Conclusions An abbreviated MRI protocol that includes only coronal T1 and STIR sequences maintains high sensitivity and specificity for hip and pelvis fracture detection and fracture classification.

Keywords Osteoporotic fractures · Hip fractures · Magnetic resonance imaging · Sensitivity and specificity

Introduction

Osteoporotic fragility fractures of the proximal femur—commonly known as hip fractures—represent a substantial public health burden. When nondisplaced, they may be occult on radiographs leading to delayed diagnosis with increased costs and worsened patient outcomes [1–5]. CT is rapid but previous studies have shown limited sensitivity [6–8]. MRI has an accuracy approaching 100% and leads to a change in management for many patients when performed after CT [6]. For these reasons, the American College of Radiology has recommended MRI for the diagnosis of the occult hip fracture [9]. However, the longer scan times may be difficult for injured elderly patients to tolerate, and emergency department (ED) physicians may be disinclined to use MRI in the time-constrained ED setting. For these reasons, an abbreviated, time-efficient MRI protocol that maintains high diagnostic accuracy for hip fracture detection but substantially reduces scanning time would be of clinical use (Figs. 1 and 2).

Two previous studies have evaluated the use of abbreviated MRI in the setting of acute hip pain [10, 11]. However, these studies have included patients with a wide range of ages and diagnoses; used a step-wise scale for normal, possible, probable or definite abnormality; and did not classify fractures or make a specific diagnosis. Moreover, fractures of the proximal femora and pelvis were pooled for analysis even though test

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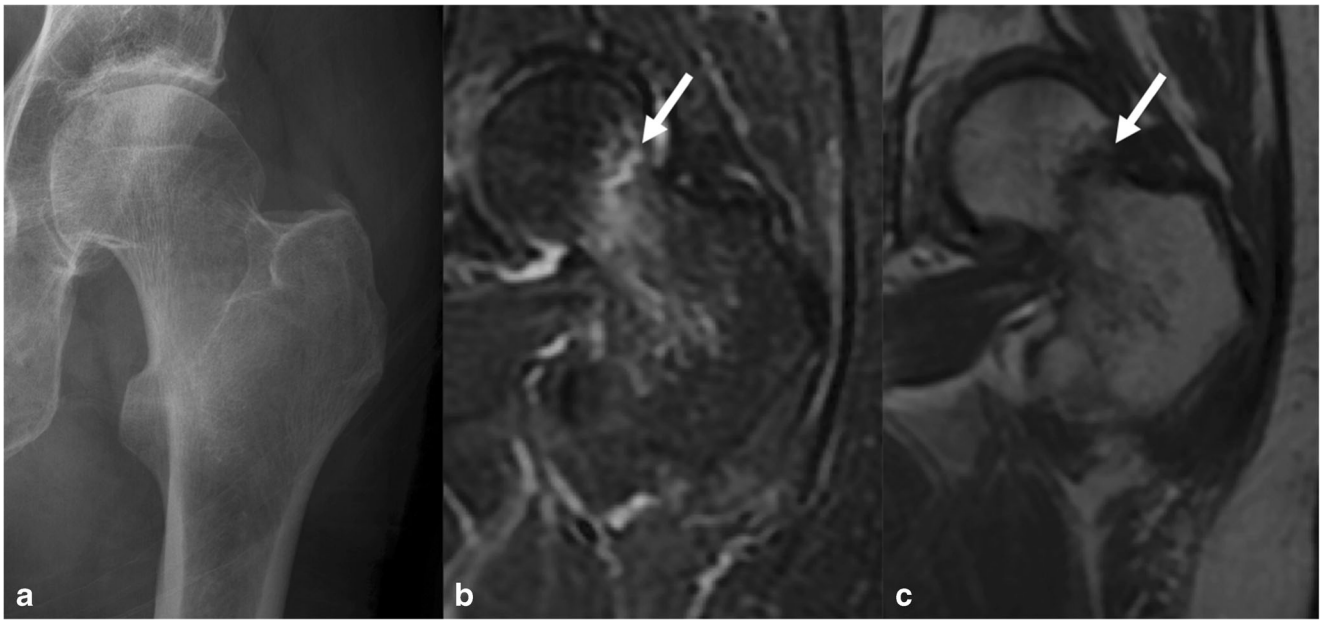

Fig. 1 A 71-year-old woman presents to the emergency department after a ground level fall. The AP radiograph of the left hip (**a**) and cross-table lateral view (not shown) were read as negative although further evaluation with MRI was recommended and subsequently obtained. Zoomed-in images of the left hip taken from large field-of-view coronal STIR (**b**) and T1 (**c**) sequences of the bony pelvis show a left femoral neck fracture with associated marrow edema (*white arrows*). The fracture could also be well seen on the axial sequences (not shown), but the correct diagnosis was made by both study readers on only the coronal images

accuracy may differ for these fracture types and the clinical consequences of missing femoral versus pelvic fractures are markedly different. Previous studies have also not reported 95% confidence intervals of their test performance estimates or pre-specified definitions of positive and negative exams as has been emphasized in more recent consensus statements such as the STARD criteria [12].

The purpose of our study was to assess whether an abbreviated MR protocol was accurate enough for practical clinical use. With this in mind, our investigation builds on previous work by evaluating the diagnostic accuracy of an abbreviated, two-sequence protocol for (a) occult hip fracture (using a binary positive or negative assessment), (b) fracture classification, and (c) soft tissue injuries. Diagnostic test accuracy is calculated separately for fractures of the proximal femora and fractures of the pelvis.

Materials and methods

This HIPPA-compliant study was approved by our institutional review board and informed consent waived for the

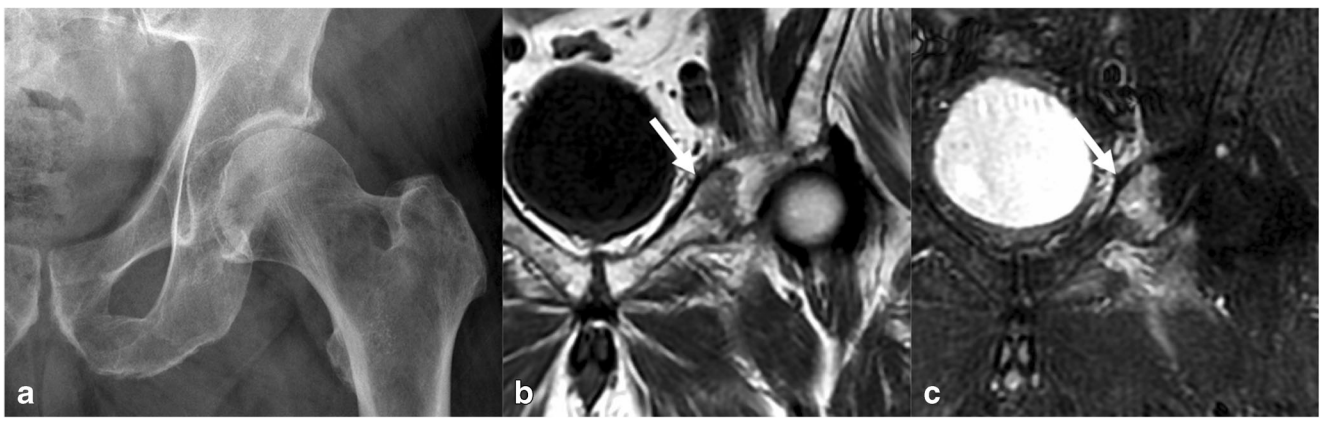

Fig. 2 An 81-year-old man presents to the emergency department with left hip pain after a ground level fall. An AP radiograph of the pelvis (**a**) and cross-table lateral view of the left hip (not shown) were read as negative. The patient was unable to bear weight and subsequent MRI was obtained. Zoomed-in images centered at the left hip taken from large field-of-view coronal STIR (**b**) and T1 (**c**) sequences of the bony pelvis show a nondisplaced fracture of the pubic root with associated marrow edema (*white arrows*) easily identified on coronal images. An ipsilateral inferior pubic ramus fracture (not shown) was also present

retrospective review of medical records. A study cohort of consecutive patients evaluated in the emergency department with hip pain and clinically suspected fracture was assembled from the time-period of 1/2/2013–7/15/2016. Our inclusion criteria were patients 65 years or older with clinically suspected hip fracture despite negative or equivocal radiographs who received a subsequent bony pelvis MRI within 48 h of initial evaluation. Patients were excluded from the study if the complete standard MRI protocol was not obtained or if there was metal hardware at the symptomatic hip. Radiographs—consisting of an AP view of the pelvis, an optional AP view of the symptomatic hip, and a cross-table lateral view of the hip—were defined as negative or equivocal on the basis of the sub-specialty trained musculoskeletal attending radiologist's final read. The decision to obtain an MRI after negative radiographs is made at the discretion of the ED physician. Demographic and descriptive statistics of the study population and tabulation of patient diagnoses were calculated and reported. The proportion of patients with difficulty during the MR scan (e.g., due to pain or delirium) was determined by review of the MR technologists' study notes.

At our institution, the complete MRI protocol in this scenario consists of the six sequences summarized in Table 1. For the abbreviated MRI protocol, we extracted only the coronal T1 and coronal short tau inversion recovery (STIR) images of the bony pelvis. These were reviewed independently by two musculoskeletal trained radiologists with 1 year (AR) and 10 years (KL) of experience. The radiologists were blinded to the diagnosis and results of the complete MRI protocol. Each reader recorded presence or absence of a fracture, classified the fracture by type, and recorded the presence or absence of any soft tissue injuries. Fractures were classified as femoral neck, intertrochanteric, greater trochanteric, sub-trochanteric, or pelvic. Pelvic fractures were not further sub-classified, as at our institution fragility fractures of the pelvis are typically treated conservatively in similar fashion regardless of sub-type. Significant soft tissue injury was defined as muscle tear, hematoma, or tendon tear. Areas of mild muscle edema without a discrete muscle tear were inconsistently described in the final report by the interpreting radiologist and were not considered significant soft tissue injuries as they would be unlikely to affect patient care. The reference standard for the diagnosis of hip and pelvic fracture, fracture classification, and diagnosis of soft tissue injuries was the final interpreting radiologist's read of the complete bony pelvis MRI protocol supplemented—when available—by review of the patients' medical records. The patients' medical records were reviewed for the 30 days following their index ED visit to ensure no fractures were missed on MRI. Thirty-day clinical follow-up was available for all but two patients in the study cohort.

Statistical analysis was performed in Stata (version 14.2, Statacorp). Sensitivity and specificity of the two-sequence, abbreviated MR protocol for fracture detection was calculated separately for proximal femoral fractures and pelvic fractures with 95% confidence intervals. Accuracy of fracture classification compared to the gold standard exam was calculated for each reader using Cohen's kappa coefficient. This was interpreted using the guidelines suggested by Landis and Koch with 0.0–0.20 as slight agreement, 0.21–0.40 as fair, 0.41–0.60 as moderate, 0.61–0.80 as substantial, and > 0.81 indicating excellent agreement [13]. The kappa coefficient was also used to assess inter-rater agreement on presence of fracture, soft tissue injury, and fracture classification.

Results

A search of the electronic health record using our inclusion criteria yielded 113 cases over the time-period of interest. Of these, one case was excluded as the symptomatic hip had metal hardware from a prior fracture fixation and one case was excluded as the MRI was obtained greater than 48 h after the initial radiographs. This left 111 cases for analysis. The mean patient age was 80 years with a range of 65–99. Seventy-five percent of the study population was female; 36% of patients had difficulty during the MR scan due to pain

Table 1 Complete MR bony pelvis protocol - sample scanning parameters (3 T)

Sequence	Repetition time/ echo time (ms)	Field of view	Echo train length	Section thickness/ gap (mm)	Matrix	NEX	Scan Time (min:s)
Bony pelvis							
Coronal T1*	575/20	Body width	4	5/2.5	320 × 192	2	2:56
Coronal STIR*	5000/40	Body width	9	5/2.5	320 × 192	2	3:09
Axial T1	575/20	Body width	4	5/2.5	320 × 192	2	3:30
Axial T2 fat-sat	4225/85	Body width	16	5/2.5	320 × 192	2	4:00
Affected hip							
Sagittal PD fat-sat	2200/42	18 × 18	6	4/1	280 × 224	2	4:00
Coronal T2 fat-sat	2800/80	18 × 18	10	4/1	280 × 224	4	5:30

*Used for evaluation in abbreviated MR bony pelvis protocol

or confusion as recorded in the technologist comments. The distribution of fracture types among study patients is shown in Table 2. All but two of the study patients had subsequent contact with our health care system with clinical follow-up of at least 30 days available for review in the electronic health record, and review of the clinical record did not identify any fractures missed by the complete MR protocol. It should be noted that overall 41% ($n = 46$) of patients had radiographically occult fractures at MRI and 11% of patients ($n = 12$) had fractures of the proximal femur that were treated surgically. One out of seven femoral neck fractures was treated conservatively because the patient was deemed a poor surgical risk. Both greater trochanteric fractures and seven of the 12 intertrochanteric fractures were treated conservatively. At our institution, surgeons will often treat intertrochanteric fractures conservatively when they do not violate the medial cortex or femoral calcar. Of the 111 study patients, 18% ($n = 20$) had significant soft tissue injuries. These included muscle tear ($n = 12$), tendon avulsion ($n = 5$), or hematoma ($n = 3$).

The accuracy of the abbreviated protocol for the diagnosis of femoral fractures, pelvic fractures, and soft tissue injuries is listed in Table 3. The kappa coefficient for evaluating accuracy of fracture classification was 0.90 for reader 1 and 0.88 for reader 2, indicating excellent agreement for both readers in their fracture classification compared to the classification made on the basis of the gold standard complete MRI protocol.

Kappa coefficient for inter-rater agreement between the two study radiologists was excellent for presence or absence of fracture and fracture classification at 0.89 and 0.84, respectively. It was substantial for presence or absence of soft tissue injury at 0.65.

Discussion

Our study demonstrates a high diagnostic accuracy for an abbreviated MRI protocol in the setting of elderly patients with clinically suspected hip fracture. In particular, the abbreviated exam remained 100% sensitive for the diagnosis of proximal femoral fractures including femoral neck fractures, which may go on to displacement if missed on initial presentation. Diagnostic accuracy was slightly less for pelvic fractures with two false-negative cases, although these fractures are typically treated conservatively. Importantly, fracture type was classified accurately on the basis of the abbreviated protocol, of relevance for treatment planning and clinical adoption of the abbreviated exam. Accuracy of soft tissue injury diagnosis was high for the included injury types of hematoma and muscle or tendon tear, which are most likely to have an impact on patient care. Maintaining a high accuracy for pelvic fractures and significant soft tissue injuries is of clinical importance, as these are common alternative diagnoses in the setting of clinically suspected hip fracture [14, 15].

Table 2 Results of the complete MR bony pelvis protocol in 111 patients with clinically suspected hip fracture and negative radiographs

Fracture classification	Gender		Total (%)
	Female	Male	
Negative	50	15	65 (59)
Pelvis	18	6	24 (22)
Intertrochanteric	9	3	12 (11)
Femoral neck	4	3	7 (6)
Greater trochanter	1	1	2 (2)
Sub-trochanteric	1	0	1 (<1)
Total	83	28	111 (100)

Our study supports and builds on the previous literature that has demonstrated excellent sensitivity for proximal femoral fracture utilizing limited pulse sequences [10]. The current study also demonstrates that specificity and accuracy of fracture classification are well maintained and that pelvis fractures and soft tissue injuries can be accurately diagnosed with the two-sequence abbreviated MRI protocol. This adds to the evidence that such an abbreviated protocol is accurate enough to be clinically useful.

The importance of establishing a rapid and accurate diagnosis in the elderly patient with suspected hip fracture has been well established in the literature [16, 17]. Timely diagnosis can reduce delays to surgery for those patients needing fracture fixation and may reduce costly cautionary admissions in patients who are found not to have a fracture [4]. The identification of non-surgical fractures and soft tissue injuries is also important allowing for appropriate conservative therapies including pain control, protected weight-bearing, and skilled rehabilitation as necessary. MRI is recommended as the most accurate imaging modality for identification of the radiographically occult hip fracture and has been shown to be a cost-effective strategy compared to CT or discharge without further imaging [18]. Nonetheless, implementation of a lengthy MRI protocol for emergency department patients remains a challenge, limiting use and contributing to delays in imaging [19]. Moreover, long scan times are poorly tolerated in the fragile, elderly patient population. Over one-third of the patients in our study had difficulty during the MR scan due to pain or confusion. Not only might this lead to excessive motion artifact, but with many scans occurring during the middle of the night, there may be an increase in the chance of delirium in high-risk patients [20]. A substantial decrease in MRI scan time while maintaining diagnostic accuracy may help to resolve these issues. It should be noted that time allotted for a diagnostic scan includes time for patient transfer and positioning, and this will not be affected by reducing the number of pulse sequences. Nonetheless, the abbreviated MRI saves at least 20 min of scanning time compared to the complete protocol.

Table 3 Diagnostic accuracy of abbreviated, two-sequence MRI compared to the full MRI protocol

	Proximal femoral fractures		Pelvic fractures		Soft tissue injuries	
	Sens. (95% CI)	Spec. (95% CI)	Sens. (95% CI)	Spec. (95% CI)	Sens. (95% CI)	Spec. (95% CI)
Reader 1	100 (84.6–100)	96.6 (90.5–99.3)	95.8 (78.9–99.9)	97.7 (91.9–99.7)	100 (76.8–100)	90.2 (78.6–96.7)
Reader 2	100 (84.6–100)	97.8 (92.1–99.7)	87.5 (67.6–97.3)	98.9 (93.8–100)	92.9 (66.1–99.8)	94.1 (83.8–98.8)

Effective emergency department care requires rapid assessment of patients, and imaging often plays a critical role in diagnosis. The utilization of MRI in the emergency department has increased significantly in recent years with an expanded list of indications [21]. Abbreviated but accurate MRI protocols make for efficient use of imaging resources providing value to the patient and the hospital. Future research may identify further ways of reducing scan time with the use of ultra-fast MR pulse sequences including isotropic acquisitions that can be reconstructed in multiple planes. In addition to decreasing overall time in the scanner, the use of these sequences may reduce motion artifact particularly when used for patients in acute pain.

Our study has several important limitations. This was a retrospective study performed at a single tertiary care academic medical center. The images were interpreted by fellowship-trained musculoskeletal radiologists. The applicability of our findings in community practice should be verified with further study. Additionally, there are no set criteria for when patients at our institution undergo MRI after negative radiographs. This is dependent on the degree of clinical suspicion of the evaluating physician and could lead to selection bias as to which patients went on to MRI and were therefore included in the study population. However, the focus of this study was on the diagnostic accuracy of the abbreviated versus complete MRI protocol, and the accuracy of the results in this cohort of patients should not be affected. The strengths of the study include strong inter-rater agreement on outcome measures and the availability of clinical follow-up for nearly all study patients allowing verification of the results of the complete MRI protocol, which was used as the gold standard. It should be noted that review of the post-imaging clinical course for the study patients did not lead to any changes in diagnosis compared to the MRI results.

MRI utilization for the assessment of patients in the emergency department will continue to grow. Efficient use of resources will require evaluation of existing MRI protocols with an eye towards minimizing scan duration while maintaining high accuracy. Our study indicates that an abbreviated MRI protocol for diagnosis of radiographically occult hip and pelvis fractures remains highly accurate and may reduce obstacles to utilization in patients with the appropriate indications.

Acknowledgements The authors gratefully acknowledge the support of the Society of Skeletal Radiology for the support of this research with the SSR Seed Grant.

Compliance with ethical standards

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Conflict of interest The authors declare that they have no related conflicts of interest. KL reports unrelated grant funding from the National Basketball Association, General Electric, RSNA Scholar Grant (RSCH1317), and Mitek and unrelated royalty income from Elsevier.

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