

Easily missed pathologies of the musculoskeletal system in the emergency radiology setting

Einfach zu übersehene Pathologien des muskuloskelettalen Systems in der Notfallradiologie

Authors

Marc-André Weber 

Affiliations

Institute of Diagnostic and Interventional Radiology, Pediatric Radiology and Neuroradiology, University Medical Center Rostock, Rostock, Germany

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Correspondence

Prof. Dr.med. Marc-André Weber

Institute of Diagnostic and Interventional Radiology, Pediatric Radiology and Neuroradiology, University Medical Center Rostock, Rostock, Germany

marc-andre.weber@med.uni-rostock.de

ABSTRACT

Background The musculoskeletal region is the main area in terms of easily missed pathologies in the emergency radiology setting, because the majority of diagnoses missed in the emergency setting are fractures.

Method A review of the literature was performed by searching the PubMed and ScienceDirect databases, using the keywords ('missed injuries' or 'missed fractures') and ('emergency radiology' or 'emergency room') and ('musculoskeletal' or 'bone' or 'skeleton') for the title and abstract query. The inclusion criteria were scientific papers presented in the English and German languages. Among the 347 relevant hits between 1980 and 2024 as identified by the author of this review article, there were 114 relevant articles from the years between 2018 and 2024. Based on this literature search and the author's personal experience, this study presents useful information for reducing the number of missed pathologies

in the musculoskeletal system in the emergency radiology setting.

Results and Conclusion Predominant factors that make up the majority of missed fractures are 'subtle but still visible fractures' and 'radiographically imperceptible fractures'. Radiologists are able to minimize the factors contributing to fractures being missed. For example, implementing a 'four-eyes principle', i.e., two readers read the radiographs, would help to overcome the missing of 'subtle but still visible fractures' and the additional use of cross-sectional imaging would help to overcome the missing of 'radiographically imperceptible fractures'. Knowledge of what is commonly missed and evaluation of high-risk areas with utmost care also increase the diagnostic performance of radiologists.

Key Points

- Radiological imaging in an emergency setting increases the likelihood of radiological diagnostic errors, such as missing musculoskeletal pathologies.
- The majority of diagnoses missed in the emergency setting are fractures.
- To lessen the number of easily missed pathologies in the musculoskeletal system in the emergency radiology setting, a systematic approach is necessary.
- Adequate training of radiologists in emergency radiology and close collaboration with clinical partners are important measures to decrease the number of missed musculoskeletal injuries.

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ZUSAMMENFASSUNG

Hintergrund Der muskuloskelettale Bereich spielt die Hauptrolle, wenn es um leicht zu übersehene Pathologien in der Notfallradiologie geht, da es sich bei den meisten Diagnosen, die in der Notfallradiologie übersehen werden, um Frakturen handelt.

Methode Eine Literaturrecherche wurde durch Durchsuchen der Datenbanken PubMed und ScienceDirect unter Verwendung der Schlüsselwörter in Titel und Abstract ('missed injuries' oder 'missed fractures') und ('emergency radiology')

oder ‚emergency room‘) und ‚musculoskeletal‘ oder ‚bone‘ oder ‚skeleton‘) durchgeführt. Einschlusskriterien waren wissenschaftliche Arbeiten, die in englischer und deutscher Sprache vorlagen. Unter den 347 relevanten Treffern von 1980 bis 2024, die der Autor dieses Übersichtsartikels identifizierte, stammen 114 relevante Artikel aus den Jahren 2018 bis 2024. Aus dieser Literaturrecherche und aus der persönlichen Erfahrung des Autors werden in diesem Beitrag nützliche Hinweise gegeben, um die Zahl der übersehenen Pathologien des Bewegungsapparates in der Notfallradiologie zu reduzieren.

Ergebnisse und Schlussfolgerung Die vorherrschenden Faktoren, die die Mehrzahl der übersehenen Frakturen ausmachen, sind die „subtilen, aber immer noch sichtbaren Frakturen“ und an zweiter Stelle die „röntgenologisch nicht wahrnehmbaren Frakturen“. Radiologen sind in der Lage, die Ursachen zu verringern, die zu übersehenen Frakturen beitragen. Beispielsweise könnte die Umsetzung eines „Vier-Augen-Prinzips“, d. h. zwei Beobachter lesen die Röntgenbilder, dazu beitragen, dass Übersehen der „subtilen, aber dennoch sicht-

baren Frakturen“ zu vermeiden, und der zusätzliche Einsatz von Schnittbildgebung würde helfen, um „röntgenologisch nicht wahrnehmbare Frakturen“ zu erkennen. Das Wissen darüber, was häufig übersehen wird, und die Bewertung von Hochrisikobereichen mit höchster Aufmerksamkeit steigern zudem die diagnostische Leistung der Radiologen.

Kernaussagen

- Die radiologische Notfalldiagnostik erhöht die Wahrscheinlichkeit radiologischer diagnostischer Fehler, wie etwa Pathologien des Bewegungsapparates zu übersehen.
- Bei den meisten in der Notfallversorgung übersehenen Diagnosen handelt es sich um Frakturen.
- Um die Anzahl leicht zu übersehender Pathologien des Bewegungsapparates in der Notfallradiologie zu verringern, ist ein systematischer Ansatz erforderlich.
- Eine angemessene Ausbildung von Radiologen in der Notfallradiologie und die enge Zusammenarbeit mit klinischen Partnern sind wichtige Maßnahmen, um die Zahl übersehener muskuloskelettaler Verletzungen zu verringern.

Introduction

Emergency imaging and radiological workup in trauma care have been reported as a “perfect storm” for radiological errors given the fact that radiologists and radiographers have to cope with factors that impair proper scanning and image interpretation, such as uncooperative patients, inadequate medical histories, time-critical decisions, and concurrent tasks (especially during night shifts or weekend shifts) [1]. The majority of diagnoses missed in the emergency setting are fractures [1]. Thus the musculoskeletal region is

the main area for missed pathologies in the emergency radiology setting. For instance, the missed injury rate in a Danish casualty department was between 0.5% and 2.2% when analyzing a cohort of $n=15,806$ [2]. In a Taiwanese emergency room department, the missed fracture rate in radiological reports was 3.7% in a cohort of $n=3,081$ [3]. The authors identified the joints as risk areas and reported the prevalence of missed fractures with the following locations: foot (8%), knee (6%), elbow (6%), hand (5%), wrist (4%), hip (4%), and ankle (3%), while in a North American pediatric emergency department the most frequently missed fractures were of the

► **Table 1** Factors contributing to missed fractures in a cohort of $n=3,081$ [3] and measures for lessening these factors.

Factors contributing to missing of a fracture	Measures for lessening the effect
Subtle but still visible fractures (37%)	Four-eyes principle, AI support
Radiographically imperceptible (33%)	Additional (cross-sectional) imaging
Block by splinting devices (7%)	Remove the splint before acquiring X-rays
Multiple fractures (9%)	Remember ‘satisfaction of search’ error*
Inappropriate or insufficient radiographs acquired (5%)	Teach radiology technologists, quality control
Lack of relevant clinical information (4%)	Talk to your clinical partners
Poorly positioned radiographs (2%)	Teach radiology technologists, quality control
Metal artifacts (2%)	Use metal artifact suppression techniques
Severe osteoporosis (2%)	Additional (cross-sectional) imaging

Note: The percentage of the aforementioned factors contributing to the missing of a fracture in the cohort of Wei et al. [3] is given in parentheses. *The ‘satisfaction of search’ error is a common error in diagnostic radiology, and it typically occurs when the reporting radiologist fails to continue to search for subsequent abnormalities after identifying an initial one, because this initial detection of an abnormality satisfies the ‘search for meaning’ and the reporting of the case is prematurely ended. In emergency medicine, ‘satisfaction of search’ errors are referred to as premature closure and this may entail identifying two or more totally independent pathologies or two or more findings which together take a case from a differential list to a definitive diagnosis [8].

hand phalanges followed by metatarsus, distal radius, tibia, and phalanges of the foot [4]. Other authors also reported that among all missed injuries, extremity fractures make up between 14% and 60% [5, 6]. Moreover, missing a fracture is the second most common error alleged in medical malpractice suits against radiologists in the United States [7]. Of note, Wei et al. also reported that 70% of initially missed fractures could be identified by a second review [3]. In addition, in this study, they described factors contributing to the missing of a fracture (► **Table 1**). The two predominant factors, which make up 70% of missed fractures, were first ‘subtle but still visible fractures’ and second ‘radiographically imperceptible fractures’. Radiologists are able to lessen the factors contributing to missed fractures. For example, implementing a ‘four-eyes principle’, i. e., two readers read the radiographs, would help to overcome the missing of ‘subtle but still visible fractures’. The emerging artificial intelligence (AI) applications may also be supportive in this respect. Also, the additional use of (cross-sectional) imaging would help to overcome the missing of ‘radiographically imperceptible fractures’. ► **Table 1** presents techniques to lessen the factors contributing to missed fractures.

Pearls of wisdom to reduce the number of missed pathologies of the musculoskeletal system in the emergency radiology setting

A review of the literature was performed by searching the PubMed and ScienceDirect databases, using the keywords (‘missed injuries’ or ‘missed fractures’) and (‘emergency radiology’ or ‘emergency room’) and (‘musculoskeletal’ or ‘bone’ or ‘skeleton’) for the title and abstract query. The inclusion criteria were scientific papers presented in the English and German languages. Among the 347 relevant hits between 1980 and 2024 as identified by the author of this review article, there were 114 relevant articles from the years between 2018 and 2024. Based on this literature search and personal experience from more than 24 years of radiological reporting and as a certified Fellow of the European Society of Emergency Radiology since 2018, information to reduce the number of missed pathologies of the musculoskeletal system in the emergency radiology setting is presented in the following.

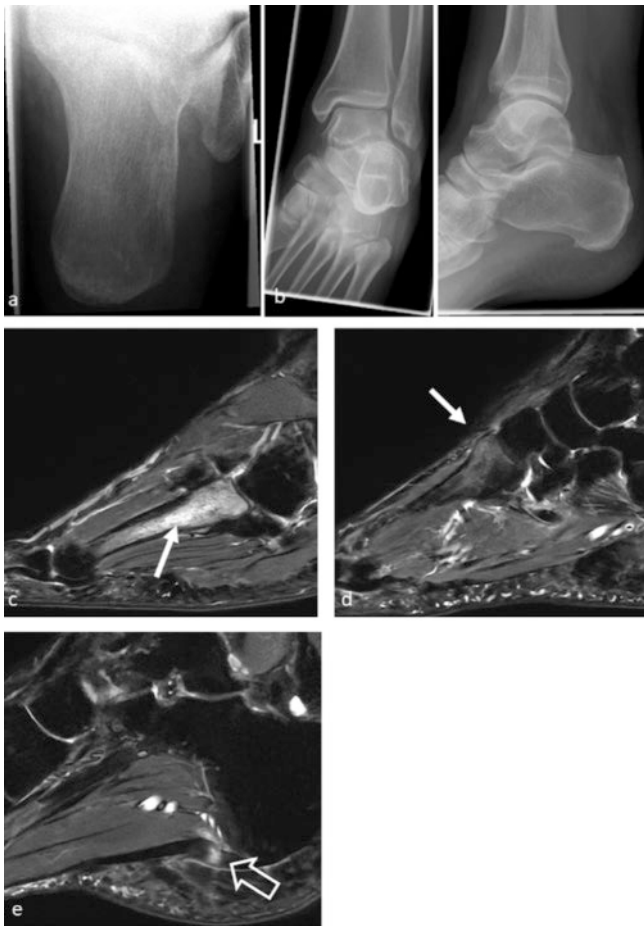
The first and, from my point of view, most important pearl of wisdom is to use additional imaging in case of doubt. ► **Fig. 1** presents a case where the fracture is radiographically occult and is only visible when using cross-sectional imaging. Radiologists know the best use of all available radiological imaging modalities and should therefore advise patients and clinical partners as to which imaging modality is appropriate for a certain clinical question. For certain clinical conditions, image or “choosing wisely” concepts including emergency imaging have been published [9]. Although radiographs are the mainstay for fracture assessment, a fracture may be missed because it is radiologically invisible or equivocal [10]. In summary, when there is a high clinical index of suspicion for a fracture despite initial negative radiographic findings, additional computed tomography (CT) or magnetic resonance imaging (MRI) examinations are recommended, particularly if the results would affect clinical management [10, 11].



► **Fig. 1** 57-year-old woman with fall on right knee and pain in the medial aspect. Radiographs on two planes (**a**: anterior-posterior, **b**: lateral view) as well as CT (**c**: coronal reconstruction with 0.6 mm slice thickness, **d**: sagittal reconstruction with 0.6 mm slice thickness) did not demonstrate a fracture. MRI (**e**: T1w-weighted sagittal sequence, **f**: proton-density fat-saturated sagittal sequence) shows the fracture of the tibial head with substantial bone marrow edema (arrows) that, also on retrospect, was not visible on both the CT and X-ray images.

The second pearl of wisdom is to perform proper imaging. This requires knowledge of the patient’s clinical information (► **Fig. 2**). The precise correlation of physical examination findings, such as the site of maximum pain, with radiologic imaging is also helpful for proper reporting [10, 11]. The benefit of sufficient clinical information to improve radiologists’ performance with respect to selection of the best imaging protocol and reporting has been advocated by both radiologists and trauma surgeons, thereby substantiating the value of close interaction [10, 12].

The third pearl of wisdom is to know the indirect signs of fracture when interpreting projection radiographs. ► **Fig. 3** shows as an example the ‘fat-pad sign’ resulting from hemarthrosis of the elbow joint as an indication of a fracture. This may especially be important in pediatric and adolescent patients. General radiologists who do not frequently report pediatric musculoskeletal cases should pay careful attention to the following five pediatric fracture types: 1. unstable fracture of the radial condyle, 2. luxa-



► **Fig. 2** 57-year-old man with fall from a ladder. The radiographs ordered initially (**a**: calcaneus, **b**: ankle joint and second plane of calcaneus and ankle joint) were reported as uneventful. Only, a minor plantar osseous spur was mentioned in the report as an auxiliary finding. Because of the fact that pain was persisting for 2 months, an additional MRI was ordered and performed 10 weeks after initial trauma. The MRI examination (**c–e**, short-tau inversion recovery (STIR) images) revealed a stress fracture of the fourth metatarsal bone (arrow in **c**) and at the base of the second metatarsal bone (arrow in **d**) as well as a slight bone bruise within the calcaneus but without a fracture line and partial tear of the plantar fascia near its insertion (open arrow in **e**).

tion of the radial head, 3. supracondylar humerus fracture with rotation, 4. proximal bowing fracture of the tibia, 5. fracture of the medial malleolus. When one of these aforementioned fracture types is overlooked, growth disturbance together with or without dysfunction may result and missing one of these fractures is often a reason for liability claims. For instance, in Northern Germany physicians are found at fault in 60% of these liability cases [13]. Of note, three of these fractures that are prone to be overlooked are situated next to the elbow joint and misinterpretation of fractures of the elbow may result in delays of consolidation with subsequent growth disturbances, joint dysfunction, and malposition. Missed fractures are common in pediatric trauma patients because of the substantial normal variation in the contour of developing bones and growth plates as well as because of the subtlety of findings or the radiographical invisibility [14]. Moreover, frac-



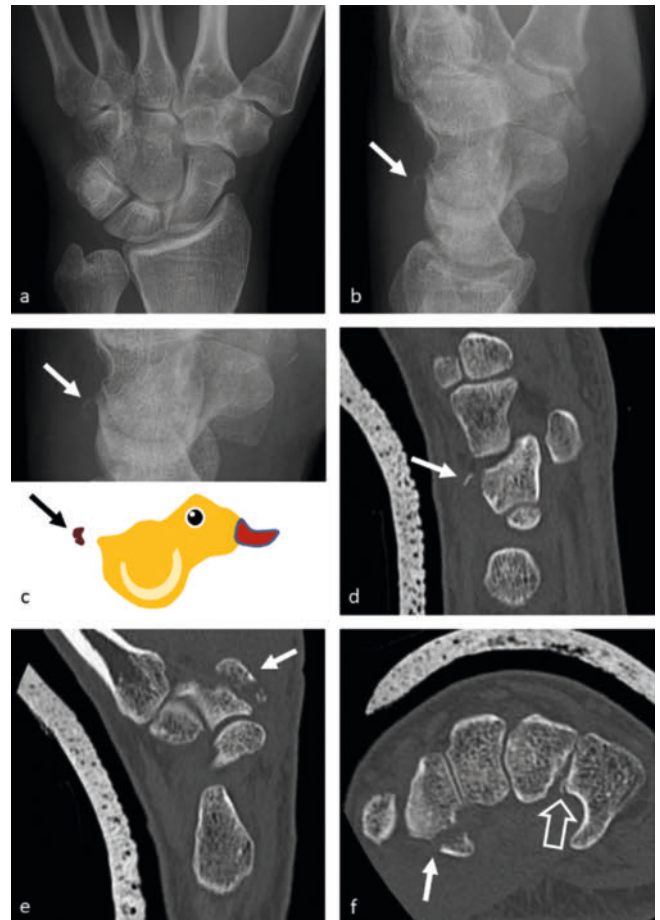
► **Fig. 3** 17-year-old male adolescent who fell while horseback riding. The externally performed X-ray in lateral projection **a** does not show a fracture (of note the radial head is superimposed by the coronoid process) but positive 'fat-pad sign' as the result of hemarthrosis (arrows). The Greenspan view performed in-house of the radial head **b** demonstrates the intraarticular, non-displaced fracture of the radial head (Mason type I, arrow) that is also shown at the sagittal reconstruction of the additional CT scan (**c**, arrow). MRI (**d**: proton-density fat-saturated sagittal sequence) shows bone marrow edema of the radial head and the distal posterior humerus (asterisks), the non-displaced intraarticular Mason type I fracture (arrow) as well as the joint effusion (open arrow) causing the 'fat-pad sign' of the initial radiograph.

tures have been reported to be the third most common diagnosis included in medical malpractice lawsuits involving children in United States emergency departments and urgent care centers [15]. Hence, knowledge of typical fractures for different ages, the individual bone nuclei of the growth plate, and epiphyseal injuries is important for the correct radiological diagnosis.

The fourth pearl of wisdom is to always acquire radiographs on two planes when trauma sequelae are suspected and to know Aunt Minnie's atlas [16], i.e. the typical (pathognomonic) imaging signs of the musculoskeletal pathologies. ► **Fig. 4** demonstrates the typical 'pooping sign' of triquetrum fractures. Triquetrum fractures are the second most common carpal fracture after the scaphoid and make up approximately 15% of all wrist fractures. They are usually the result of forced hyperflexion. Dorsal triquetrum fractures are most common and they are most often caused by avulsion from the attachments of dorsal radiocarpal ligaments, whereas transverse or sagittal fractures of the triquetrum body are far less common. They have been reported to occur in association with a variety of different mechanisms, including crush injuries and perilunate fracture dislocations. As a rule of thumb, the routine wrist series is usually sufficient for fracture identification. On X-ray, dorsal triquetrum fractures are seen only on the lateral projection since the pisiform usually overlies and obscures the triquetrum on the anterior-posterior projection of the

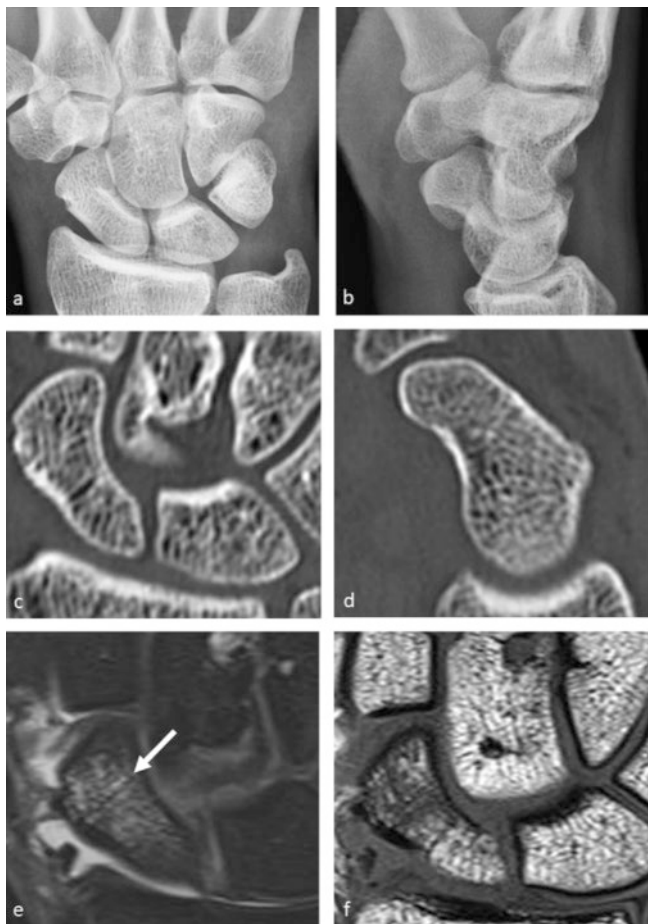
wrist. In summary, many fractures are visible on only a single view. Therefore, there is a risk of a false-negative interpretation of a radiographic examination if not all necessary views are obtained, thus substantiating the role of standardized protocols with two or more planes [11].

The fifth pearl of wisdom is to know the limitations of the selected imaging modality. The radiologist's role is to perform imaging wisely and radiologists know the pros and cons of each available imaging modality better than their clinical partners (also see the first pearl of wisdom). A good example of emergency radiology of the musculoskeletal system where knowledge of the limitations of each imaging modality is mandatory is when determining whether a scaphoid fracture is present. Scaphoid fractures account for almost 80% of all carpal fractures and fractures in the middle third of the scaphoid are the most common at around 60%. The typical trauma mechanism is a fall on the outstretched hand [17]. The proper role of radiological imaging is not only to detect or rule out a scaphoid fracture, but also to answer the question of fragment stability. The basis is conventional radiography with three projections: dorsopalmar, lateral, and Stecher image (the scaphoid is aligned parallel to the detector plane by closing the fist and ulnar deviation). However, radiography only has a sensitivity of $\leq 70\%$. Hence, the early use of cross-sectional imaging is crucial to avoid missing a scaphoid fracture. In German-speaking countries, high-resolution CT is initially recommended using thin slices from 0.5 to 0.75 mm and oblique-sagittal and oblique-coronal image reconstructions parallel to the longitudinal axis of the scaphoid [18]. The advantage of CT is the superior, therapy-relevant representation of the fine bony structures including the exact fragment dislocation (specificity 100%). The sensitivity of CT for detecting fractures is only about 95%, i.e., a non-displaced fracture can escape detection. If a fracture is clinically suspected and the X-ray and CT results are negative, additional MR imaging must be carried out (► Fig. 5). In the Anglo-American region, MRI is usually used immediately after the X-ray procedure with thin slices of 1.5 or 2.0 mm and at least one slice plane parallel to the scaphoid. MRI is advantageous because it detects all scaphoid fractures based on trauma-induced bone marrow edema (sensitivity 100%). The disadvantage of MRI is that it is often difficult to differentiate between a bone contusion ("bone bruise") and a fracture (specificity around 85%), which is why CT imaging must be supplemented [17]. In summary, the early use of high-quality CT and/or MRI avoids delayed diagnosis of a scaphoid fracture given the fact that up to 30% of acute scaphoid fractures are missed on conventional radiography. Another often overlooked fracture of the wrist is the hook of hamate fracture [19], since standard radiographs often fail to diagnose hamate fractures [10]. For an early diagnosis, when there is a high index of suspicion, the key is to perform carpal tunnel projections or CT scans early [10, 19]. The question as to whether there is a Lisfranc fracture is an example of often missed trauma sequelae in the lower extremities. The lack of weight-bearing views can lead to false-negative radiographic findings [11]. After midtarsal trauma, initial radiographs are typically non-weight-bearing anterior-posterior, lateral and internal oblique views [10]. A high index of suspicion is key since 20% of Lisfranc fractures are missed at first presentation, especially when no additional weight-bearing



► **Fig. 4** 41-year-old man with pain in the left wrist after a fall on flexed hand while ice skating. The anterior-posterior radiograph **a** does not show a fracture. The lateral radiograph **b** depicts a tiny osseous fragment on the dorsal side of the carpal bones (arrow). The “pooping duck sign” (arrows, **c**) indicates a triquetrum fracture (drawing courtesy of Henning Maschke, Hamburg). The CT scan (**d**: sagittal reconstruction with 0.625 mm slice thickness) better demonstrates the typical “pooping duck sign” of the triquetrum fracture but in addition reveals a fracture of the tubercle of the trapezium bone (arrows; **e**: sagittal and **f**: paratransverse reconstruction of the CT dataset with a 0.625 mm slice thickness), as well as cortical flakes of the hamate bone (open arrow) and capitate bone (not shown). The fractures of the trapezium, hamate bone, and capitate bone were not visible on the radiographs.

radiographs have been performed [10, 20]. It is important to look for misalignment on radiographs and to use CT scans early [21], since CT's superiority to conventional radiography in the diagnosis of bony disorders of the Lisfranc joint has been demonstrated [22]. Hence, on radiographs, the congruence between the cuneiform bones and the cuboid bone with the metatarsal bones should always be inspected closely and since findings are usually very subtle, additional cross-sectional imaging may be necessary for safe exclusion (► Fig. 6). In addition, osseous injuries and especially avulsion fractures in growing adolescents may be overlooked when using solely projection radiography as the imaging modality. Avulsion fractures are typical between the ages of 12 and 22 years and they represent overworking of the im-



► **Fig. 5** Non-displaced scaphoid fracture in a 34-year-old man after a fall on the left hand. The radiologist reporting the initial radiographs (**a**: anterior-posterior, **b**: lateral view) presumed a non-displaced scaphoid fracture and recommended an additional CT examination. The CT scan performed the same day did not reveal a fracture and thus an additional MRI examination was recommended when pain would persist (**c**: coronal and **d**: oblique-sagittal image reconstruction parallel to the longitudinal axis of the scaphoid). In the MRI examination performed 13 days after initial radiographs because of persisting wrist pain (**e**: proton-density fat-saturated and **f**: T1-weighted coronal sequences), the fissure (arrow) and the bone marrow edema within the scaphoid bone could be depicted.

immature skeleton. Knowing the risk areas and checking for asymmetry will help to avoid overlooking osseous avulsion injuries [20]. Besides avulsion injuries, other osseous injuries in growing adolescents that may be underestimated on projection radiography are transitional fractures. Transitional fractures are special forms of epiphyseal injuries in adolescents in whom the growth plate is already partially closed. Due to the partial ossification, specific stereotypical fracture patterns can develop and can be differentiated into biplane, triplane I, and triplane II fractures, depending on the involvement of the metaphysis and the number of fragments. At the beginning of the diagnostic cascade, conventional projection radiography on two planes is used. However, due to the complex fracture patterns, CT is often indicated and necessary for preoperative planning. Prognostically relevant is above all the reconstruction of the joint surfaces, as early arthrosis



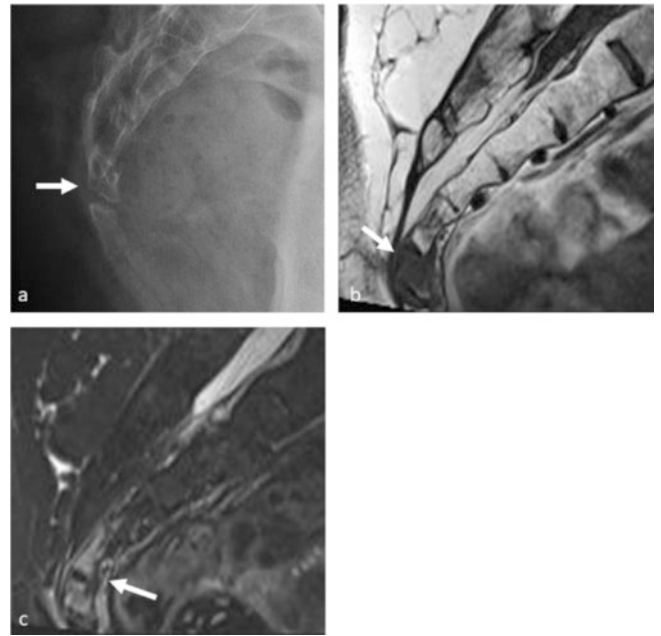
► **Fig. 6** 18-year-old man with radiographs of the left foot after crush injury. The initial radiographs (non-weight-bearing anterior-posterior (not shown), internal oblique views **a**, and lateral **b**) have been reported as uneventful. The patient received an MRI examination seven days later showing injury of the Lisfranc joint (arrows, **c**: T1-weighted and **d**: proton-density weighted fat-saturated sequences) and CT performed 9 days after the initial radiographs (**e**: transverse and **f**: sagittal reconstruction) best demonstrates the several small osseous flakes around the tarsometatarsal joints (arrows) and the avulsion fractures of the lateral and intermediate cuneiform, navicular, and cuboid bones as well as the bases of the second and third metatarsal bones.

can be a risk if the incongruity remains [23]. Therefore, although the use of CT should be restricted in children, CT plays an important role in proper preoperative assessment in the case of transitional fractures. The role of CT scans is to recognize the complexity of transitional fractures and epiphyseal injuries of partially closed growth plates, because injuries of growth plates may be hard to detect on radiographs [23]. In summary, especially in an emergency setting, radiologists should recommend supplementary imaging procedures, such as cross-sectional imaging, to detect radiographically imperceptible injuries or fractures that are difficult to classify on radiographs. Radiologists best understand the limitations of radiography for certain diagnoses and thus can best recommend more advanced imaging to establish a correct diagnosis in a reasonable time frame [10].



► **Fig. 7** Second fracture in a 56-year-old man after knee distortion. In the radiographs in anterior-posterior **a** and lateral projection **b**, the small osseous flake is only visible on the anterior-posterior projection (arrows in **a** and the zoomed inset **c**). The MRI examination demonstrates rupture of the anterior cruciate ligament (arrow, proton-density fat-saturated sagittal sequence **d**), partial rupture of the medial collateral ligament (arrow), avulsion of the anterior lateral capsule (open arrow), and bone marrow edema within the lateral femoral condyle (asterisk; proton-density fat-saturated coronal sequence **e**), as well as a fracture of the dorsal tibial plateau (arrow, T1-weighted sagittal sequence **f**).

The sixth pearl of wisdom is to look for subtle findings. The Second fracture is a very good example of a subtle finding on projection radiography that typically indicates a severe trauma and major damage that only cross-sectional imaging can identify (► **Fig. 7**). A Second fracture is a vertically oriented avulsion fracture at the lateral tibial plateau, predominantly caused by a varus force on the knee when the foot is firmly planted [20]. It is common in running athletes. MRI may reveal a bone contusion of the medial femoral condyle and the posteromedial tibial plateau. Second fractures are associated with anterior cruciate ligament tears in 75–100% of cases and lateral meniscal tears in 33% of all cases [20]. This fact explains why it is so important not to overlook the often tiny osseous avulsion injuries on projection radiography. In summary, small avulsion fractures may be easy to overlook and, as in the Second fracture, they indicate major injuries [11]. Fractures of the coccyx are another example of subtle findings and



► **Fig. 8** 54-year-old woman after fall on buttocks 2 weeks ago with persisting pain. The coccyx fracture of Co1 is visible on the radiograph (arrow, **a**), but could be easily overlooked. MRI (**b**: sagittal T1-weighted and **c**: sagittal STIR sequence) demonstrates the fracture-related bone marrow edema (arrows) of Co1 and Co2.

coccydynia is one of the most overlooked symptoms in clinical practice (► **Fig. 8**). The most common cause of coccydynia is trauma, e. g., from water slides and falls, and radiologists should be familiar with the coccyx's morphologic appearance and with morphologic parameters and hypermobility causing coccydynia [24].

The seventh pearl of wisdom is to know the bone nuclei when reading pediatric radiographs. Common misinterpretations of pediatric radiographs are due to the numerous epiphyses and apophyseal nuclei as well as accessory bone nuclei, because these are partly interindividual and, depending on the level of development of the child, can imitate bony fractures or fragmentations in the case of ignorance of age-specific X-ray anatomy. One typical example is the lateral apophysis at the base of the fifth metatarsal bone. This lateral apophysis, depending on the projection, is relatively distant from the base to the representation. It should be noted that fractures of the fifth metatarsal base typically proceed horizontally and a pure rupture of the apophysis is extreme rare [25] (► **Fig. 9**). It is also helpful in this context to look at the relevant atlases illustrating the numerous epiphyses and apophyseal nuclei as well as the accessory bone nuclei of the growing skeleton.

The eighth pearl of wisdom is a really straightforward and obvious one: always look at all available images. ► **Fig. 10** presents a case within the field of spine fractures illustrating the importance of always also reviewing the CT scout views. Spine fractures have been reported to be difficult to diagnose, especially on radiographs due to superimposing structures, and missing them can be associated with increased neurologic injury and resulting morbidity [26]. Reports from the literature underline the fact that the scout views should always be read. Otherwise, the missing of 2–5% of pathologies in CT examinations has been reported with

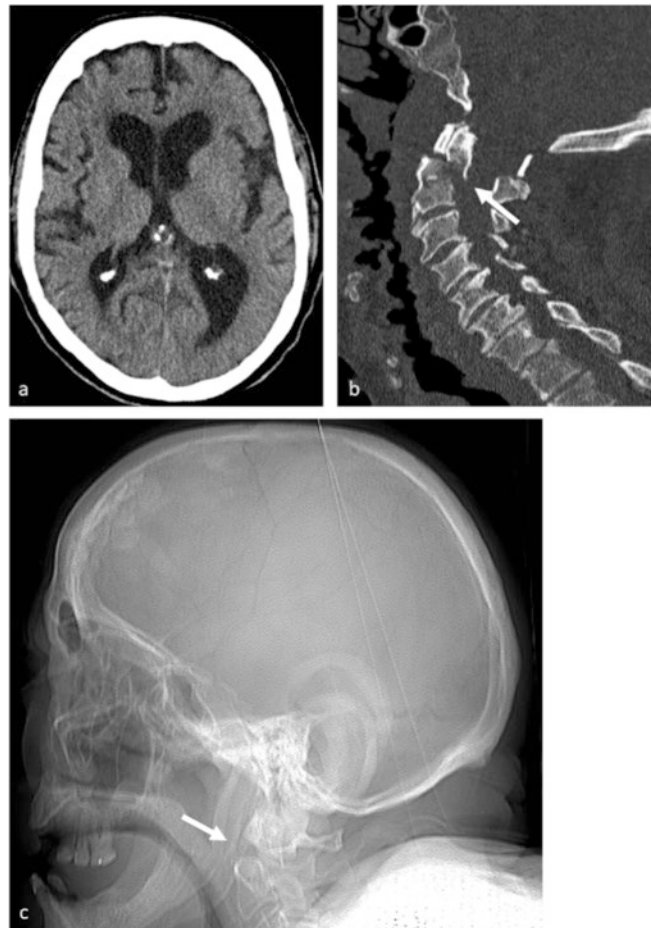


► **Fig. 9** Fracture of the base of the fifth metatarsal in a child (courtesy of Christina Hauenstein, Rostock). The arrow points at the vertically oriented apophyseal nucleus of the fifth metatarsal bone, while the open arrow indicates the more horizontal course of the fracture line.

obvious negative medicolegal and ethical considerations [1, 27, 28, 29]. In summary, scout images are an integral part of any CT examination and thus should be carefully reviewed for findings that may or may not be included in the field-of-view of the study.

The human factor

Humans can get tired. This obvious statement is also true for all medical professionals including radiologists. A Scandinavian study has assessed the total number of correctly diagnosed and missed fractures per hour of a day and they observed that the rate of missed fractures surpassed the number of correctly diagnosed fractures between 5 p.m. and 7 a.m., i.e., during the night shifts [30]. Other studies have also reported that on-call duty is a factor contributing to the missing of fractures and other injuries [31, 32]. Other factors include a lower level of experience on the part of the reader (most on-call duties are performed by radiologists in training) and image interpretation under stressful conditions in the emergency room [10], lack of clinical information, absence of previous imaging studies, suboptimal reading room atmosphere, multitasking and increased workload [10] – all factors that are often typical of on-call duties and night and weekend shifts. Another human factor is perceptual errors when reporting radiological images [33, 34]. The ‘satisfaction of search’ error [8, 11] (► **Table 1**), where the detection of an abnormality results in premature termination of the search for further issues, is one of these. In other words, fractures are missed on radiological images, for instance, because other fractures are found. Another perceptual error and form of incomplete search pattern is visual iso-



► **Fig. 10** 83-year-old man with dementia who fell on his head in the nursing home. He received anticoagulation because of known atrial fibrillation. The initial CT scan performed at the emergency department was reported as no traumatic brain injury and no fracture **a**. The patient was transferred from trauma surgery to the neurological department of the tertiary care hospital and the suspected diagnosis was worsening of the dementia. A follow-up cranial CT scan was performed the next day because of distinctive behavioral changes of the patient at the neurological ward. Also, the follow-up CT scan the next day was reported as no traumatic brain injury and no fracture (not shown). After another 4 days, the patient presented with further clinical worsening, respiratory insufficiency and paresis of his left arm. Another cranial CT scan was ordered again showing no brain ischemia or bleeding (not shown) but suspicion of a fracture of the odontoid process of the second cervical vertebra was raised. The patient was then transferred back from neurology to trauma surgery and a CT scan of the cervical spine six days after the first presentation demonstrated the dislocated fracture (arrow) of the odontoid process of the second cervical vertebra **b**. Of note, when thereafter reviewing again all radiologic images, the scout views of the first **c** and second (not shown) CT scan both show the fracture of the odontoid process (arrow) and it became evident that some radiologists of the team unintentionally had the routine presentation of scout views deactivated in their PACS settings. The latter was then fixed for the entire team and the case was presented in an interdisciplinary morbidity and mortality conference.

lation, where the search pattern of the radiologist is truncated to the main areas of an image, while little or no attention is given to peripheral areas. Inattentive blindness can also be included as a perceptual error. It is defined as the failure to notice a fully visible, but unexpected object because attention was otherwise engaged [34]. These errors are also the reason why delayed diagnoses were not recognized on subsequent radiologic examinations in about one third of cases [35]. Perceptual errors combined with time pressure are especially challenging in the reading of whole-body CT scans of polytrauma patients. For instance, although osseous wrist and hand injuries are present on about 12% of whole-body CT scans after polytrauma, about 93% of these injuries were missed primarily in a recent study on 506 polytrauma CT scans resulting in a diagnostic accuracy of 6.8% for the primary reporting [36]. The authors additionally mentioned that motorcycle accidents predispose for these injuries and often cause additional fractures of the extremities [36]. Furthermore, the presence of more than two injured body parts has been identified as an independent predictive factor for missed injury [37]. Moreover, missed injuries have been reported to be more likely in severely injured and intubated patients [38] and missed foot injuries have been especially reported to occur in patients having been in car accidents or having fallen from great height [39]. Besides fractures, there are non-skeletal injuries (such as parenchymal injuries) and non-traumatic incidental findings (such as neoplastic findings) that are common and, given the aspects mentioned above, can also be easily overlooked on polytrauma CT scans. For example, abdominal injuries are potentially life-threatening and occur in 20–25% of all polytraumatized patients with the liver (40%) and spleen (32%) as the most commonly injured parenchymal organs [40]. In addition, incidental imaging findings unrelated to trauma that require urgent treatment or further clarification have been reported in 8.4% of all patients, most frequently in the thorax and in the abdominal/pelvic region, in a study on 2,440 patients with multiple trauma undergoing whole-body CT at admission [41]. Approximately 40% of these patients had incidental findings requiring either immediate or delayed treatment/follow-up with the most frequent findings being lesions suspicious for malignancy or definite malignancies as well as inflammation [41]. Disregarding severity, the most common incidental findings in the aforementioned study were mucosal swelling/chronic sinusitis (20%), healed fractures (10%), renal cysts (10%), hepatic steatosis (9%), and hepatic cysts (9%) [41]. To overcome these problems, the standardized use of the ‘four-eyes principle’, clinical re-evaluation, a second review of radiological imaging, and/or artificial intelligence (AI) support may be advantageous. For example, re-evaluation of existing imaging as part of tertiary surveys, i.e. the re-examination of patients after emergency care typically within 24 hours of admission [6, 36, 39], significantly reduces the number of missed fractures and other injuries [42, 43].

The potential of artificial intelligence

An important and intriguing aspect is the emerging role of AI. There are now numerous AI-based solutions on the market de-

signed to assist radiologists in reporting, akin to a ‘four-eyes principle’. Applications of AI for image interpretation in the musculoskeletal region consist of the determination of body composition measurements, bone age, identification of fractures, screening for osteoporosis, evaluation of segmental spine pathology, detection and temporal monitoring of osseous metastases, diagnosis of primary bone and soft tissue tumors, and grading of osteoarthritis [44, 45]. The number of publications per year in PubMed using the keywords (‘artificial intelligence’ and ‘fracture’ and ‘radiology’) has increased steadily from 30 publications in 2019 to 151 publications in 2023, and several AI algorithms, specifically deep learning algorithms, have been applied to fracture detection and classification, which are potentially helpful tools for radiologists and clinicians [46, 47, 48]. For instance, it has been reported that AI has the potential to automate and improve the accuracy of scaphoid fracture detection on radiography, thereby aiding in early diagnosis and reducing unnecessary clinical examinations, as well as reducing the risk of missed fractures and complications and reducing reading time and observer fatigue [49, 50, 51]. It should be noted that the combination of AI and the radiologist’s analysis provided the best results regarding wrist fracture detection in a recent study including 1,917 radiographs [52]. As another example, a recent multicenter study including 600 adult patients with multi-view radiographs after a recent trauma demonstrated that the AI aid improved the sensitivity of physicians by 8.7% and their specificity by 4.1% and reduced the mean reading time by 15.0% [53]. Besides the assessment of fractures in the emergency radiology setting, deep learning algorithms have been used to detect, for instance, free fluid on Focused Assessment with Sonography for Trauma, to identify intracranial hemorrhage on head CT scans, and to identify injuries to organs like the spleen, liver, and lungs on abdominal and chest CT [54]. It should be noted that AI is not replacing radiologists but could be especially helpful to optimize workflow and augment diagnostic performance [46, 55, 56], particularly in light of increasing workloads and staffing shortages, which require radiologists to review more images, particularly cross-sectional ones.

Conclusion and take-home message

In conclusion, one take-home message regarding the lessening of the number of easily missed pathologies of the musculoskeletal system in the emergency radiology setting is that a systematic approach is necessary in emergency and trauma care [20]. Some pearls of wisdom and measures have been summarized for this purpose in this review article. It is important to quickly evaluate the high-risk areas first (and maybe to re-evaluate them in a second look) and to know what is commonly missed [20, 33]. The categories of missed fractures that should be remembered are [33]: a) ‘common but challenging’ (e.g., *scaphoid fracture*), b) ‘out of mind out of sight’ (e.g., *reviewing the scout view*), and c) ‘satisfaction of search’ (e.g., *polytrauma such as motorcycle accidents*). Strategies for mitigating perceptual errors such as the ‘satisfaction of search’ are, for example, the use of checklists, self-prompting routines, and structured reporting within an institutional culture of safety and vigilance [34, 57]. In addition, case conferences

focusing on missed findings may enhance radiological training, because it is easier to see what you know to look for and, of course, it is easy to miss what you do not know [33]. Moreover, in the emergency radiology setting, the initial modality that is used and the patient populations that are involved have to be considered. For example, different strategies are necessary for polytrauma CT scans compared to conventional hand X-rays for elderly patients after a fall. The pearls of wisdom mentioned in this review article help to address this issue. For all these reasons, radiologists should be and continue to be adequately trained in emergency radiology, thereby providing an invaluable service to clinical colleagues by ensuring that patients do not suffer from delayed diagnoses [10]. For this purpose, the Emergency Radiology working group of the German Radiological Society was founded in Germany in 2023 [58]. On an European level, the European Society of Emergency Radiology (ESER) was founded in 2011 with the goal of providing emergency radiology training and certification. One particular aim of ESER is to advance and improve radiological aspects of emergent patient care and to advance the quality of diagnosis and treatment of acutely ill or injured patients using imaging, by among others providing polytrauma imaging guidelines [59] and by offering a dedicated curriculum that certifies a subspecialty in emergency radiology with a European diploma [60]. Last but not least, multidisciplinary meetings (e. g., morning meeting of radiologists together with trauma surgeons to review the cases of the night shift) are effective for detecting missed fractures.

Conflict of Interest

The authors declare that they have no conflict of interest.

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