Journal of the Pediatric Orthopaedic Society of North America 7 (2024) 100037

Contents lists available at ScienceDirect

Journal of the Pediatric Orthopaedic Society of North America

journal homepage: www.jposna.com

Current Concept Review

Updates in pediatric upper extremity imaging

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A R T I C L E I N F O

Keywords:
Upper extremity
Forearm
Imaging
Fluoroscopy
Radiographs
Ultrasound

A B S T R A C T

Minimizing radiation exposure is crucial for both patient and provider safety. The harmful effects of ionizing radiation are well-documented. Further research is necessary to effectively decrease these risks. The present study compiles the most recent data available from orthopaedic surgery and radiology literature, with a focus on pediatric upper extremity imaging. The purpose of this study is to give a comprehensive update in order to improve patient and provider safety and guide future research.

Radiographs are the most commonly employed imaging modality in the upper extremity, and there is a wealth of articles focusing on optimizing its use in pediatric patients. Recommendations include utilizing in-room fluoroscopy for final imaging after closed forearm fracture reduction in the emergency department and foregoing formal post-reduction radiographs. Additionally, literature supports that early postoperative radiographs and radiographs after pin removal in patients who have undergone closed reduction and percutaneous pinning of supracondylar humerus fractures do not change management. Similarly, pediatric patients who have been treated for musculoskeletal infection do not require follow-up radiographs, in the absence of clinical concern. Other imaging modalities, such as ultrasound, computerized tomography (CT), and magnetic resonance imaging (MRI) have expanded their indications in pediatric upper extremity injuries in recent years. This includes ultrasound for diagnosing fractures and tendon pathologies, new CT technology that decreases radiation exposure, and MRI scans with potentially safer contrast agents.

In summary, research has been expanding our understanding of radiation exposure and exploring ways to minimize this during pediatric upper extremity imaging. Further research is necessary to facilitate safer diagnostic tests in pediatric patients.

Key Concepts:

(1) Fluoroscopy should be utilized as definitive post-reduction imaging after closed reduction of pediatric forearm fractures.
(2) Radiographs do not need to be obtained in the early-postoperative setting or after pin removal in patients who have undergone closed reduction and percutaneous pinning of supracondylar humerus fractures.
(3) Only obtain follow-up radiographs if there is a clinical concern in pediatric patients who have been treated for a musculoskeletal infection.
(4) The application of ultrasound, CT scan, and MRI are continuing to expand and improve in pediatric upper extremity pathologies.

Introduction

The advent of radiographs in 1895 by Wilhelm Roentgen revolutionized medicine. They allowed noninvasive visualization of previously unseen problems, which changed the treatment of orthopaedic problems and eventually became the impetus for creation of an entire specialty devoted to imaging. With time, these imaging modalities improved and expanded, to include things such as computerized tomography (CT) and magnetic resonance imaging (MRI) scans. However, we have also gained knowledge of the harmful side effects that radiation can cause to the human body, which has raised awareness about this issue. In the past few decades, the usage of imaging has increased significantly, and reports have shown that Americans were exposed to 7 times as much ionizing radiation in 2006 as they were in the 1980s [1].

Healthcare professionals, particularly those within the fields of radiology and orthopaedics, are tasked with the duty of minimizing

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https://doi.org/10.1016/j.jposna.2024.100037
Received 27 March 2024; Accepted 27 March 2024
Available online 4 April 2024

radiation exposure to patients while also providing the highest level of care possible. This is exponentially amplified in the pediatric population, where cells are still rapidly dividing and therefore more vulnerable to the effects of ionizing radiation. Reducing radiation exposure can occur in several forms, including new technology, limiting unnecessary imaging, or changing protocols. Not only do changes in imaging affect patient radiation exposure, but there are also potential benefits with regard to time and economic savings, as well as increasing the availability of these resources for other purposes. There has been a significant amount of research that has focused on this in recent years, creating a rapidly changing landscape.

The purpose of this paper is to synthesize available information from prominent journals in orthopaedic surgery and radiology which included *The Journal of Bone & Joint Surgery*, the *Journal of the American Academy of Orthopaedic Surgeons*, the *Journal of Pediatric Orthopaedics*, *The Journal of Hand Surgery*, *Radiology*, and the *American Journal of Roentgenology*. We focused on radiation reduction strategies for pediatric orthopaedic patients, with a focus on the upper extremity. By doing so, we hope to provide knowledge for all providers, including surgeons, emergency care providers, and radiologists, in order to optimize safe and effective care for this population.

Body

Imaging modalities

Radiographs

Radiographs are the most commonly used imaging modality and are typically the go-to first line of imaging during work-up and often used for follow-up imaging. Therefore, they offer the most potential for radiation exposure as well as interventions to decrease this exposure risk in the pediatric population.

This begins with initial evaluation before diagnosis is made. For example, elbow injuries are a common complaint within the pediatric population, typically occurring after a fall. Oftentimes, work-up includes multiple views of the elbow, along with the forearm and potentially humerus, to determine a diagnosis and treatment plan. A recent study by Schlacter and colleagues aimed to determine whether developing a specific imaging protocol for these patients would reduce the number of x-rays performed, while not missing any injuries [2]. Their protocol included 3 major recommendations: "(1) evaluating injury with at most 2 contiguous areas of radiographs, (2) limiting screening for secondary fractures except for children with elbow injuries, and (3) not repeating or obtaining additional imaging without clear clinical concern" [2]. Once implemented, this protocol was found to significantly decrease the number of x-rays obtained, with the largest reduction occurring after elbow injuries [2].

Once a diagnosis is made, then decisions regarding treatment are addressed. Unlike adults, the majority of upper extremity fractures can be treated without surgery. Oftentimes, a closed reduction under sedation is required prior to splint or cast placement. Many providers obtain formal radiographs after reduction/cast placement, in order to confirm that the reduction has been maintained and alignment is adequate, however, this is an additional source of radiation exposure for these children. This also increases the total time of the emergency department encounter. Recent studies have shown that using fluoroscopy, or a mini c-arm, for definitive post-reduction imaging, is safe and more cost-effective than utilizing formal radiographs, without an increased need for re-reduction or surgery [3,4]. Fig. 1 shows a distal radius fracture treated with closed reduction and casting. Fig. 2 shows post-reduction images obtained utilizing fluoroscopy.

Previous studies have shown that utilizing the mini c-arm reduced patient radiation exposure from an average of 50.0 mrem with standard radiographs to 14.0 mrem [4]. In a 2020 study, Goodman and colleagues further examined outcomes after implementing a standardized emergency department protocol to determine time savings and rate of

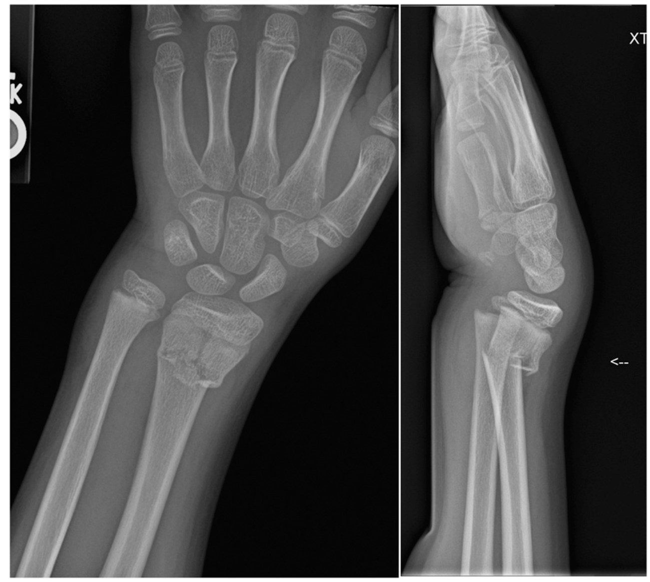

Figure 1. Posteroanterior (PA) and lateral wrist radiographs in an 11-year-old male after sustaining a distal radius fracture.

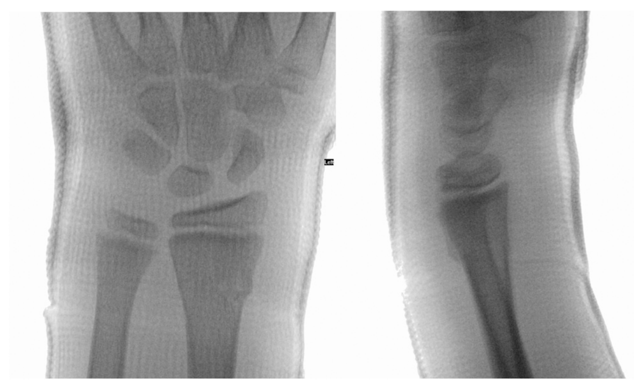

Figure 2. PA and lateral fluoroscopic views obtained after closed reduction and casting of the patient in Fig. 1.

re-reduction or surgery [5]. Their study found that utilizing fluoroscopy as post-reduction imaging decreased the total emergency department encounter time by 33 minutes while having no impact on need for re-reduction or future surgery [5]. *Taken together, fluoroscopy should be used as definitive post-reduction imaging after a closed reduction is performed in the emergency department, which saves time, money, and decreases patient radiation exposure.*

After pediatric upper extremity fractures are treated, whether or not it be with surgical intervention, repeat radiographs are typically obtained at follow-up visits to determine loss of reduction, fracture healing, and physis integrity. Again, this poses an additional occurrence of radiation for the child. One specific area that has gained recent interest is in the follow-up after surgically treated supracondylar humerus fractures. Three papers on this exact topic have been published in the past 3 years. The first was a retrospective study by Zusman et al. that examined 100 children who underwent closed reduction and percutaneous pinning of a supracondylar humerus fracture and obtained standard radiographs at time of pin removal and then again at least 3 weeks later [6]. No patients in this study had their fracture management changed based on the post-pin removal radiographs, and they therefore suggest that these do not provide any significant clinical meaning [6]. Fig. 3 shows a type III supracondylar humerus fracture that was treated with percutaneous pin fixation, as seen in Fig. 4 and Fig. 5 shows radiographs that were taken after pin removal.

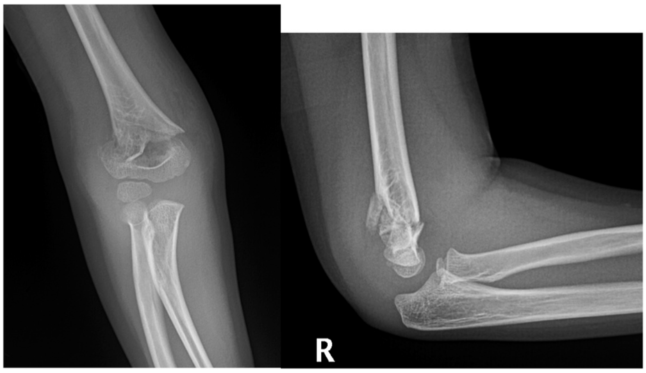

Figure 3. Anteroposterior (AP) and lateral elbow radiographs of a 6-year-old male who sustained a right type III supracondylar humerus fracture.

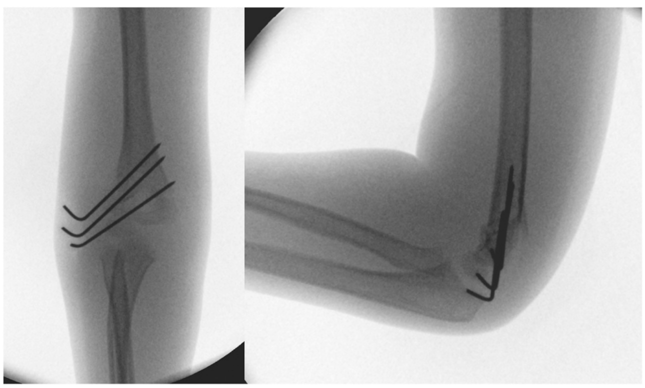

Figure 4. Closed reduction and percutaneous pinning of the supracondylar humerus fracture seen in Fig. 3.

Figure 5. AP and lateral elbow radiographs obtained after pins were removed from patient seen in Figs. 3 and 4.

The previous study was later followed up by a systematic review examining the utility of postoperative radiographs after supracondylar humerus fractures. Using the 8 papers included in their study, they found a 1% risk of change in fracture management based on post-operative radiographs [7]. The third study by Acosta et al. reviewed 412 patients and categorized them based on time to first follow-up (1 week vs 3–4 weeks), to determine whether early radiographs and follow-up affected outcomes [8]. They did not find any significant difference in complications between the 2 groups, and only 2 patients (0.5%) in the cohort who were seen for a 1-week follow-up had a change in management based on that visit [8]. *These studies suggest that early, 1 week follow-up, as well as radiographs after pin removal, are likely unnecessary after closed reduction and percutaneous pinning of supracondylar humerus fractures.*

Some supracondylar humerus fractures (type I fractures) are treated with cast immobilization alone, given the inherent stability of the fracture. Currently, there is not a standardized clinical and radiographic follow-up for these nonoperatively treated fractures. In order to help determine what type of follow-up is necessary, Zakrzewski and Ferrick retrospectively reviewed 489 children with nondisplaced supracondylar humerus fractures [9]. Their study found that none of these patients had a change in management based on radiographs that were obtained after the cast was removed, and less than 5% of patients (n = 14) required a change in management based on follow-up after cast was removed, with the vast majority being for range of motion evaluation [9]. They suggest that both clinical and radiographic follow-up after the cast is removed are likely not required. This same thought process is being applied for other common, nonoperative pediatric fractures. For example, Brown and colleagues changed the standardized radiographic follow-up for nonoperative clavicle fractures from 2 views to 1 view and found a significant reduction in the number of clavicle radiographs taken [10]. They also applied a similar concept to pediatric metatarsal fractures in their study, and this protocol of reduced radiographic views, highlighting that this could be applied to other nonoperatively treated pediatric fractures.

Outside of fracture management, follow-up radiographs may be obtained for other diagnoses, such as osteomyelitis or septic arthritis. Gajewski and colleagues examined the utility of follow-up radiographs after these conditions [11]. They retrospectively reviewed 131 patients with confirmed osteoarticular infections who had routine radiographic follow-up. Of these routine radiographs, only 2 (0.7%) detected a negative sequela (ie, growth disturbance, pathologic fracture or recurrent infection), resulting in 143 radiographs as the number needed to screen [11]. When examining reactive radiographs, or those that were obtained due to clinical concern, they found that 5.1% revealed negative sequelae, with a number needed to screen of 20 radiographs [11]. *They recommend obtaining follow-up radiographs after musculoskeletal infection only if there is a clinical concern, rather than as routine surveillance.*

Ultrasound

The use of ultrasound has grown over the past several years. It has the capability of visualizing both bone and soft tissue, while also holding the capability of performing dynamic evaluations. It is safe and noninvasive, with no radiation exposure, however quality of image is user-dependent and often requires specialized training to perform and read ultrasounds. Regardless, indications have been expanding. A recent review article by Litrenta et al. discusses the use of ultrasound in pediatric orthopaedics [12]. Examples include diagnosing forearm fracpirating joint effusions. One benefit of ultrasound over radiographs, is that you can visualize the cartilage surface, which significantly impacts the treatment decisions in pediatric patients. Another benefit of ultrasound is the potential for dynamic examination [13]. In the upper extremity for example, pathologies such as biceps tendon or extensor carpi ulnaris tendon subluxation (Figs. 6 and 7) can be inconclusive on MRI but are well demonstrated on ultrasound [14].

Acknowledging the learning curve associated with reading ultrasounds, a recent study aimed to examine if the addition of transverse ultrasound images to standard radiographs would improve treatment plans in lateral humeral condyle fractures, given that there is often a large cartilaginous component [15]. They concluded that the use of ultrasound significantly changed the proposed treatment plan, and that the interobserver reliability increased after training [15]. The application of ultrasound in pediatric orthopaedics will likely continue to expand as more providers become comfortable using and interpreting the ultrasound.

CT

It is well known that CT scans subject patients to increased doses of radiation. Previous studies have shown that radiation dosage received

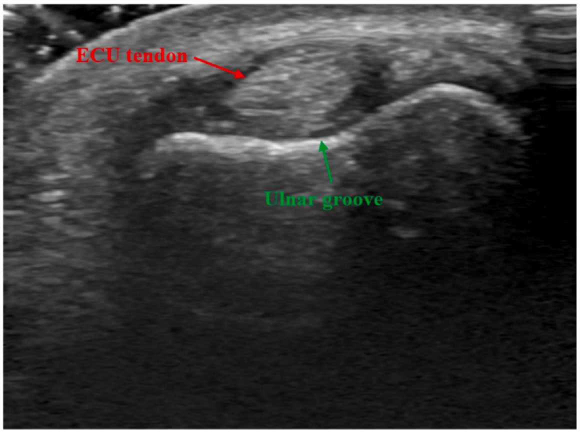

Figure 6. Transverse ultrasound cross-section of the extensor carpi ulnaris (ECU) tendon as it sits within the ulnar groove during neutral forearm rotation.

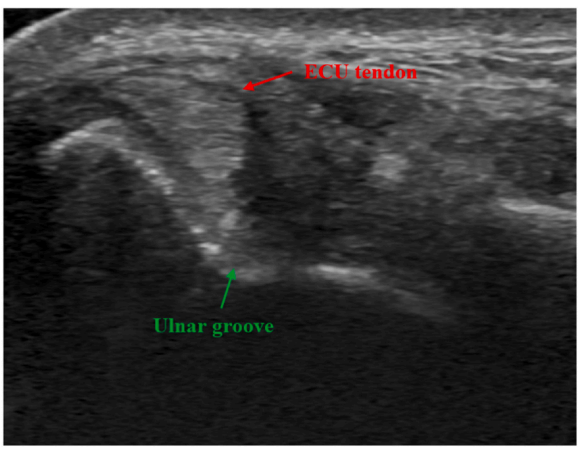

Figure 7. Ultrasound showing subluxation of the ECU tendon out of the ulnar groove during forearm supination.

decreases as you move further away from the axial skeleton, with wrists receiving less than elbows, which receive less than shoulders [16]. However, the decision to order a CT scan, particularly in a pediatric patient, should not be taken lightly. Fortunately, CT scans have been a focus of recent research which has led to improvement in this technology. One of the more recent advances are cone beam CT scans, which allow improved spatial resolution with lower radiation dose [17]. Additionally, within the past few years, photon-counting detector CT (PCD) has been developed, which has technical advantages over conventional CTs that allow for improved spatial resolution, lower image noise, and potentially lower acquisition doses to achieve the same level if image quality [18,19]. Cao and colleagues highlight these features in one of the first uses of PCD CT in the pediatric population [20]. In the upper extremity, high-resolution CTs of the wrist on PCD-CT can be achieved with up to 50% dose reduction compared to conventional CT scans [21] (Fig. 8).

While clinical applications of PCD CT are still in their infancy, the potential for usage in the upper extremity and all of orthopaedics is vast.

Additionally, the implementation of deep learning-based image reconstruction has recently been shown to reduce the impact on image noise in image quality, as such, allowing for lower acquisition doses in pediatric patients undergoing CT scans [22]. In their study of 65 children, Nagayama et al. compared deep learning-based reconstruction with standard iterative reconstruction algorithms, and found a significant dose reduction with similar or improved image quality in the deep learning-based cohort [23]. *The opportunity for advancement in image quality and safety in pediatric CT scans is something that will likely continue to grow.*

MRI

While MRI scans do not emit ionizing radiation, they do pose risks to pediatric patients in the form of anesthetic and contrast use. MRIs can take anywhere between 15 and 90 minutes to perform. Many children, in particular younger children, are unable to lie still for that duration, and image quality is highly dependent upon the patient not moving for the entirety of the scan. This leads to the need for sedation in pediatric patients undergoing MRI. Recent research has focused on predicting the needs for anesthesia in pediatric MRIs, as a way to provide guidance and possible reduction in anesthetic exposure. One study by Machado-Rivas et al. detailed multiple predictors for longer MRI scan time and propofol exposure, including higher American Society of Anesthesiologists (ASA) classification, oncologic diagnosis, 1.5 Tesla magnet, use of IV contrast, and multiple body parts examined [24]. This knowledge is helpful information as we go forward trying to improve the safety of pediatric MRIs.

Aside from anesthetic exposure, MRIs can also provide undue risk to children through contrast usage. Aside from concerns with clearance in patients with impaired kidney function, there has become increasing concern with intracranial deposition of gadolinium [25]. One recent study describes the use of ferumoxytol as a contrast agent in MRI, which is biodegradable and shows no risk of nephrotoxicity or tissue retention [26]. Their study describes multiple off-label uses for this contrast medium, including for bone and soft-tissue tumors as it shows differential enhancement between benign and malignant lesions [26].

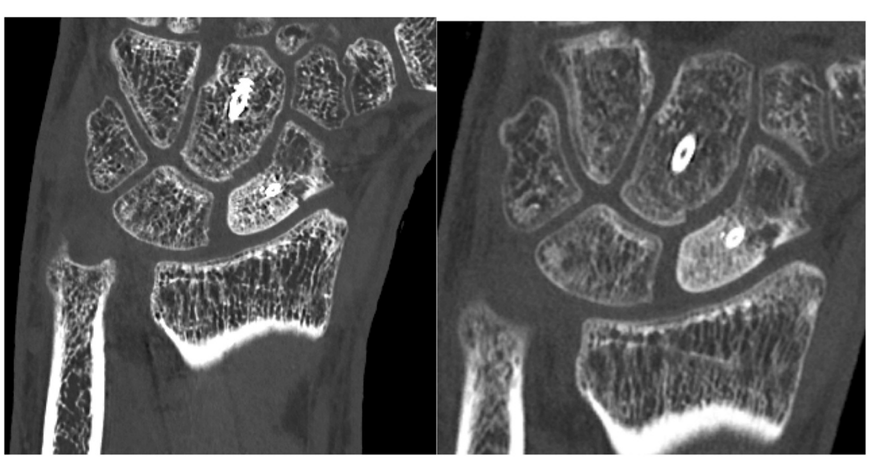

Figure 8. Twenty-three-year-old male with healing scaphoid fracture. PCD-CT (A) and energy-integrating detector (EID)-CT (B) of the right wrist both scanned on the same day. Cortical and trabecular features are more distinct on the PCD-CT image. PCD-CT, photon-counting detector-computerized tomography.

Ferumoxytol shows significant promise as a safe alternative to gadolinium-enhanced MRIs, particularly in the pediatric population.

Summary

Within the past 3 years, there has been significant research focusing on decreasing the risks associated with pediatric imaging. This includes protocols to decrease the number of radiographs taken at time of injury and during follow-up, implementation of ultrasound in fracture care, more specialized CT scans that decrease radiation exposure, and improving the safety of MRIs. We hope that this review can serve as a synopsis to all providers caring for pediatric patients with the common goal of enhancing care, as well as invoke further research in this field.

Additional links

- AAOS OVT: Pediatric X-ray Assessment.
- AAOS OVT: Dynamic Ultrasound With Anatomic Correlation of the Wrist and Hand.

Funding

No funding was necessary for this manuscript.

Ethics approval and consent

No human or animal subjects were utilized in this study.

Consent for publication

All authors have consented to publication of this work.

Availability of data and materials

All data and materials included in this study are readily available to the public.

Author contributions

Francis Baffour: Conceptualization, Methodology, Supervision, Writing – review & editing. **Lauren E. Dittman:** Conceptualization, Methodology, Visualization, Writing – original draft. **Nicholas Pulos:** Conceptualization, Resources, Supervision, Writing – review & editing. **Anika Dutta:** Conceptualization, Writing – review & editing.

Declarations of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

None.

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