JPOSNA

Volume 5, Number 3, August 2023

Original Research

Decreasing Radiation Exposure in the Treatment of Pediatric Long Bone Fractures Using a DXA Scan: A Proof of Concept

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Received: August 25, 2022; Accepted: June 14, 2023; Published: August 1, 2023

DOI: 10.55275/JPOSNA-2023-564

Abstract

Background: Fractures are typically evaluated and monitored using plain radiographs, but in the pediatric population the goal is always to reduce radiation exposure when possible. Dual-energy X-ray absorptiometry (DXA) is an imaging modality that uses less radiation. The evaluation of upper and lower extremity fractures in the pediatric population using DXA imaging has not yet been studied.

Method: Radiographs of 19 patients treated for forearm or tibia fractures were compared to images taken with a DXA machine. The angulation and translation of the fractures were measured twice each by two independent observers. Correlation of these values between plain radiographs and DXA scans along with intra- and inter-observer reliability was calculated.

Results: A total of 19 patients with a forearm or tibia fracture were enrolled in the study. Correlation with conventional radiographs for angulation was $r=0.77$, $p<0.001$, while for translation was $r=0.76$, $p<0.001$. The mean difference between the methods was 0.5 degrees (range of -6.7 to 7.7) for angulation and 4% (range of -28% to 37%) for translation. For plain radiographs the inter-rater reliability was 0.90 (95% confidence interval of 0.84-0.93) for angulation and 0.89 (0.68-0.95) for translation. The inter-rater reliability for DXA imaging was 0.77 (0.69-0.83) for angulation and 0.76 (0.41-0.88) for translation.

Conclusion: Our study showed that DXA imaging correlates well with plain radiographs when measuring angulation and translation of forearm and tibia fractures in the pediatric population. This study is a proof of concept that DXA, a low-dose radiation alternative to plain radiographs, may be useful in the management of pediatric fractures.

Level of Evidence: Level III

Key Concepts

- Decreasing radiation exposure in the pediatric population is an ongoing goal in pediatric orthopaedics.
- Fracture follow-up imaging in the pediatric population currently is mainly restricted to plain radiographs.
- A lower dose imaging modality might be an alternative to plain radiographs to monitor long bone fracture alignment.

Introduction

Plain radiography is the most common imaging modality used to diagnose and manage fractures. The risk of radiation associated with plain radiography has been well-documented, especially in regard to carcinogenesis and teratogenesis, among other complications.[1-5] Radiation in the pediatric population is especially concerning, as highly mitotic tissue is more susceptible to the effects, which places this population at greater risk.[6] This is compounded by the longer life span of children, allowing for the accumulation of radiation effects. CT scans can triple the risk of leukemia and brain cancer depending on the dosage used in the pediatric population.[2] The overall risk of cancer induction from all types of radiographs is 10 times higher in children than adults.[5] Given the higher risk in the pediatric population, it remains important to continue to explore imaging modalities that use a lower effective radiation dose in line with the concept of As Low As Reasonably Achievable (ALARA).[3] Our aim was to compare dual-energy X-ray absorptiometry (DXA) to conventional radiographs for the follow-up evaluation of forearm and tibia fractures. We performed this study as a proof of concept that the necessary information for treating fractures of long bones can be obtained with less radiation than is currently used.

Material and Methods

This study received institutional review board approval. Pediatric patients under the age of 18 years with extra-articular fractures of the radius, ulna, and tibia were included. Enrollment criteria included fractures visible on plain radiograph. Exclusion criteria included patients greater than 18 years old, radiographically healed fractures, or patients with fractures at multiple sites. Enrollment only included patients initially undergoing nonoperative management; however, eventual surgical management was not an exclusion criterion. All patients were seen in the outpatient clinic for management of their injuries and enrollment was performed at that time.

After enrollment, patients had AP and lateral views using plain radiographs and DXA imaging of the affected extremity. The two imaging modalities were performed on the same day. All images were obtained without a cast or splint. The plain radiographs were taken using the institution's standard protocol. For the AP view, the forearm was in the anatomic supinated position. The lateral view was taken perpendicularly with the arm in the same position. All tibia and fibula views included the ankle and knee. The DXA imaging was performed using the same positioning (Figure 1).

Angulation was measured between lines drawn along the diaphysis of the proximal and distal fragments. Translation was calculated as a percentage of the total bone width at the level of the fracture. Translation of 100% or greater indicated there was no bony apposition between the proximal and distal fragments. The radius and ulna bones were measured separately. Measurements of radiographs were performed using Fuji Synapse software and its associated tools, while DXA studies were measured on paper using a ruler and

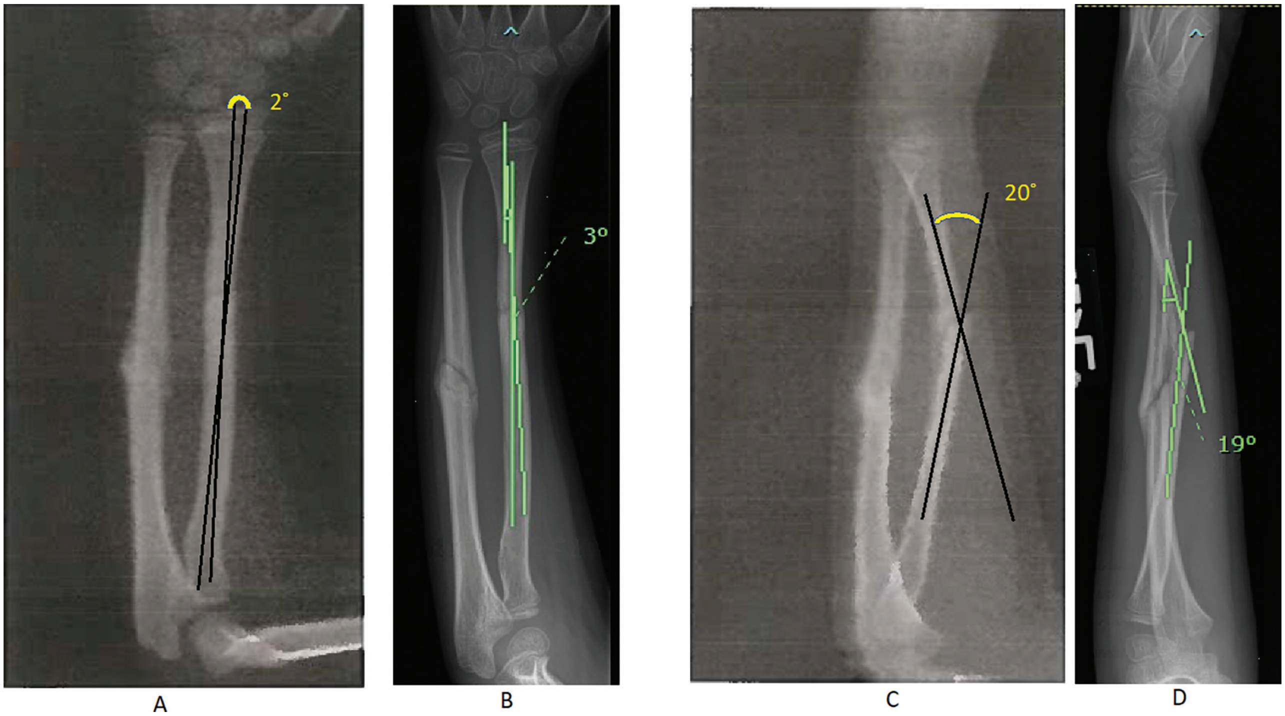

Figure 1. *An example of measurements from a DXA and radiograph of the same patient. For illustrative purposes, only the angulation of the radius is shown. For DXA measurements, these images were printed onto paper, lines were drawn with a ruler, and the angles were measured with a goniometer. Radiographs were measured using the PACS software. Panel A and C are the anterior-posterior (AP) and lateral of the DXA images. B and D are the AP and lateral of the radiographs.*

protractor. Our DXA studies are not archived into the PACS system, and there is no measurement software on the DXA machine. All images were measured twice by two independent observers at different time points to allow for intra- and inter-observer reliability calculations.

Statistical Analysis

All statistics were conducted using SPSS software. In this study, the intra-class correlation coefficient (ICC) was used to measure inter-rater and intra-rater reliability for the X-ray and DXA scan measurements. Each measurement was taken four times, twice each by two reviewers. A two-way random-effects model based on single ratings and absolute agreement was used to assess the inter-rater and intra-rater reliability. Mean estimation along with 95% confidence intervals (CI) was reported for each ICC. ICC values were interpreted as poor (< 0.40), fair (0.40–0.59), good (0.60–0.74), and excellent (0.75–1.0) reliability.[7]

In order to assess the agreement between the two continuous measurements, we used a Bland-Altman analysis.[8] A Bland-Altman analysis has been accepted as the standard statistical approach to assess the agreement between two methods of clinical measurement. In this approach, for each patient, the new method (DXA scan) measurement is subtracted from the standard method (X-ray), representing the "measurement error" observed with that patient. The mean of these differences is computed along with a standard deviation. A 95% tolerance bound (mean+/-1.96S D), known as "limits of agreement," was then computed. If the limits of agreement are within or narrower than the clinically acceptable measurement error, we could conclude that the new method (DXA scan) is well agreed with the standard method (X-Ray) and can be used instead of the standard method.

Of note, analysis of both forearm and tibia fractures was combined for the purposes of our study given the sample size.

Results

A total of 19 patients, 3 with tibia fractures and 16 with forearm fractures, were enrolled in this study. The average age at time of injury was 8.6 years (5.0–12.5 years). Images used for this study were obtained on average 27.6 days (19–54 days) after injury. Summary of this data is detailed in Table 1.

The correlation for angulation was 0.77 (p<0.001) (Figure 2). For percent translation, the correlation was 0.76 (p<0.001) (Figure 3).

A repeated measure Bland-Altman was used to analyze agreement between the radiograph and DXA scan. For angulation of fractures, the mean difference was 0.5 degrees with a 95% limit of agreement of -6.7 to 7.7 degrees (Figure 4). This indicates that on average the measured angulation on DXA imaging was 0.5 degrees greater when compared to the same measurement obtained on plain radiographs. The mean difference for

Table 1. Demographic Information

Demographic information	
Age at time of injury (years)	8.6 (5.0-12.5)
Time from injury to study imaging (days)	27.6 (19-54)
Tibia fractures	3
Forearm fractures	16

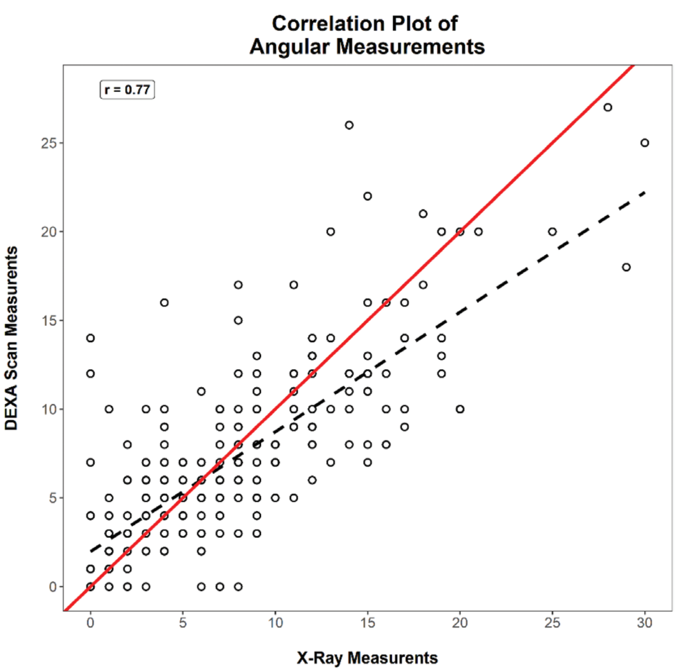

Figure 2. Correlation plot between X-ray and DXA scan of angular measurements.

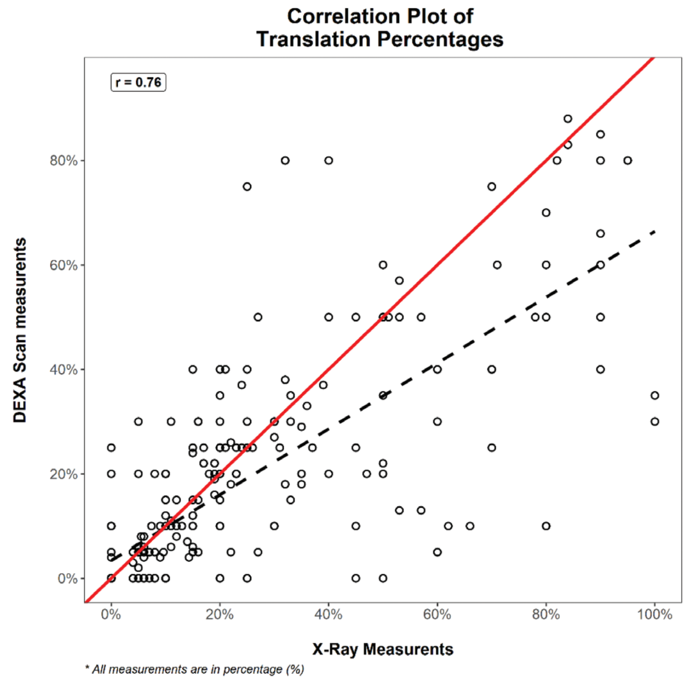

Figure 3. Correlation plot between X-ray and DXA scan of translation percentage measurements.

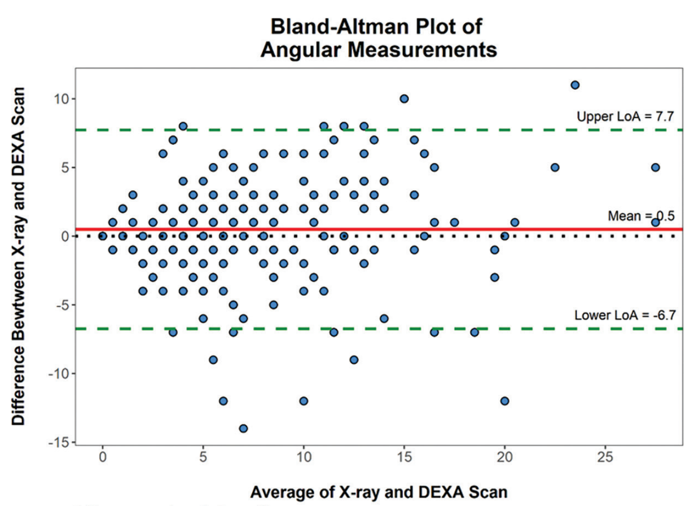

Figure 4. Bland-Altman agreement plot between X-ray and DXA scan of angle measurements.

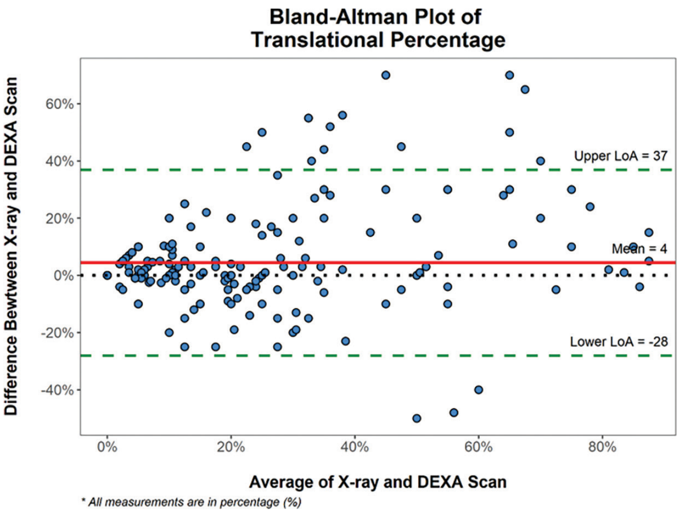

Figure 5. *Bland-Altman agreement plot between X-ray and DXA scan of translation percentage measurements.*

translation was 4% with a limit of agreement of -28% to +37% (Figure 5).

Intra- and inter-observer reliability were reported as intra-class correlation coefficient with a 95% confidence interval in order to aid in demonstrating validity of our measurements. All of the correlation coefficients were greater than 0.75, indicating excellent reliability. Full results of intra-observer and inter-observer reliability are shown in Table 2.

Discussion

The goal of this study was to provide a proof of concept that DXA imaging could be used to monitor fracture alignment. The driving force behind this is to reduce the amount of radiation in line with the concept of ALARA in the pediatric population.[3] While radiation is necessary to provide quality care, it does come with risks, especially for disease processes requiring serial radiographs over years. Children with osteogenesis imperfecta have an additional cancer risk of 0.0088% compared to the general population due to conventional radiograph and CT exposure.[9] Pediatric patients with scoliosis have been noted to have a cumulative effective dose 15mSv with a lifetime attributable cancer risk of 0.08-0.17% in Asian and Western populations.[10] If children in this population do eventually have surgery for scoliosis, they have a tenfold higher median cumulative radiation dose than those who were managed conservatively.[11]

Interventions to lower radiation doses include the use of well-trained personnel to decrease the number of images taken.[4] Technological improvements have led to improved image quality using less radiation.[1,5,6,12] The EOS system (EOS imaging, Paris, France), the most significant innovation in recent years, uses biplanar stereoradiography to produce images with low radiation. In the pediatric scoliosis population the use of EOS shows a mean reduction of 2.72 mSv or 0.91 years of background radiation over a 4.5 year follow-up.[13] The EOS machine is for standing spine and lower extremity films and therefore is not currently a replacement for traditional radiographs of the upper extremities.

We measured an average difference for angulation between conventional radiology and DXA of less than 1 degree. The mean difference for translation was only 4%, although the range included differences up to 37%.

Table 2. Intra- and Inter-Rater Reliabilities Between Measurements

Reliability (N=76)	X-ray measurements		DXA scan measurements	
	Angle ICC (95% CI)	Translation % ICC (95% CI)	Angle ICC (95% CI)	Translation % ICC (95% CI)
Intra-rater reliability				
Rater 1	0.94 (0.91, 0.97)	0.98 (0.96, 0.99)	0.92 (0.87, 0.95)	0.94 (0.90, 0.96)
Rater 2	0.96 (0.93, 0.97)	0.96 (0.93, 0.97)	0.93 (0.89, 0.96)	0.97 (0.96, 0.98)
Inter-rater reliability	0.90 (0.84, 0.93)	0.89 (0.68, 0.95)	0.77 (0.69, 0.83)	0.76 (0.41, 0.88)

Using plain radiographs as the standard, DXA tends to overestimate both the angulation as well as translation of fractures in comparison to conventional radiographs. However, the margin of error with DXA is small and likely within the acceptable range when a physician is making the decision of pursuing nonoperative versus operative management.

The proof of concept of alternatives to conventional radiology in the pediatric trauma population is the aspect of our study that differs from what currently exists in the literature. As previously discussed, EOS is an imaging modality that has reduced radiation in the pediatric population. However, it is not typically used for the acutely injured population that we examined. DXA imaging has been explored in the pediatric population but in limited capacities. Similar to its use in adults, DXA imaging is well-established as mean to assess bone density in children.[14-16]

There are several limitations to this study. Firstly, the study population was small, which may limit the generalizability of our findings. Additionally, while all images were taken within 2 months of the injury, there was no standardized time point that was used. The measurement techniques were also not the same for the two different modalities. The radiographs were measured with PACS software, but the DXA images were measured on paper because of technological limitations. In an attempt to reduce the impact of this limitation, multiple observers performing multiple measurements were performed. Finally, our study did not directly measure radiation dosing to allow for direct comparisons between conventional and DXA modalities. However, there is pediatric specific data in the literature to inform this gap. A 2016 study looking at pediatric spinal fractures found an effective dose of 41.9µSV for DXA in comparison to 232.7µSV for conventional radiographs.[17] Another study examining pediatric spinal morphometry showed an effective radiation dosage of 12.1µSV for DXA and 325µSV for conventional radiographs.[18] Lastly, a study looking at evaluation of bone age by imaging the left hand showed DXA imaging required 0.06µSV vs. 1µSV for conventional radiographs.[19] Based on this data, it is clear that the radiation dose from a DXA image is far less than conventional radiographs. While our study is not implying DXA imaging should replace conventional radiographs, we provide evidence that long bone fractures can conceivably be monitored with less radiation.

Conclusion

In this study, we were able to demonstrate that DXA scans in the pediatric population for forearm and tibia fractures correlate well with traditional radiographs in the assessment of angulation and translation. DXA scans provide enough information for follow-up care in the treatment of long bone fractures in children. This is an important proof of concept given the concept of ALARA. The goal of this study was not to advocate for replacing conventional radiography, but to further the conversation and stimulate investigation into lowering the radiation required to treat pediatric long bone fractures.

Disclaimer

No funding was received. The authors report no conflicts of interest related to this manuscript.

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