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ORIGINAL ARTICLE

Pediatric scaphoid fracture: diagnostic performance of various radiographic views

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Abstract

Purpose The purpose of this study was to systematically investigate the performance of different radiographic views in the identification of scaphoid fractures in children.

Methods and Materials This case-control study compared 4-view radiographic examinations of the wrist between children with scaphoid fracture and age- and sex-matched children without fractures performed between January 2008 and July 2019. After randomization, each examination was reviewed 3 times, at least 1 week apart, first using each view separately and later using multiple views without (3-view) and with the posteroanterior (PA) scaphoid view (4-view), to determine the presence or absence of a scaphoid fracture. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated with inter-rater agreement.

Results The study group of 58 children (48 boys and 10 girls; mean age 13.1 ± 2.1 years) included 29 with scaphoid fractures (8 corner, 9 distal pole, 10 waist, and 2 proximal pole) and 29 without fractures. Multiple views had higher sensitivity (3-view, 93.0%; 4-view, 96.5%) for fracture identification when compared to individual views (41.0–89.6%). The oblique view was 100% specific for the identification of a scaphoid fracture, but it lacked sensitivity. The PA scaphoid view had the highest sensitivity (89.6%) and NPV (90%) when compared to other individual views and its inclusion in the 4-view examinations produced the highest inter-rater agreement (93%, $\kappa = 0.86$).

Conclusion Multiple radiographic views of the wrist with the inclusion of a PA scaphoid view (4-view) produced the highest sensitivity, NPV, and inter-rater agreement for the identification of a scaphoid fracture in children.

Keywords Children · Diagnosis · Fracture · Imaging · Pediatric · Radiographs · Scaphoid

Introduction

Scaphoid fractures are the most common fractures of the carpus [1]. The incidence of scaphoid fracture is steadily rising among children and adolescents due to a combination of earlier and increased participation in youth sports [2, 3] and improved fracture detection methods [4–7]. While adult fractures commonly involve the waist (middle third of the body) of the scaphoid, which is best profiled on the posteroanterior (PA) scaphoid view, the predominant fracture location in children changes with age. Distal fractures are more common among younger children while waist fractures are more common among older adolescents [1, 4, 5, 8–16]. This age-dependent change in the fracture pattern has been postulated to be the result of the relatively weaker osteochondral junction of the immature scaphoid when compared to the surrounding soft tissue structures [4, 8, 17], which makes it more prone to injury from traction and shear, producing peripherally located fractures [6, 16, 18–20].

Radiographs remain the preferred first imaging modality of choice to screen patients with suspected scaphoid fracture because magnetic resonance imaging (MRI) is typically not readily available, incurs a higher cost, and may require sedation for younger children [5, 21]. While the published

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literature emphasizes the negative impact that delayed diagnosis and improper immobilization can have on long-term outcome [10, 15, 22], there are currently no guidelines on the optimal number of images or preferred radiographic views to best identify scaphoid fractures in children and adolescents. No published study has systematically evaluated the diagnostic accuracy of each radiographic view or the impact that the PA scaphoid view has on the identification of these fractures. The latter is important as it is often more challenging to optimally position and maintain the acquired position in children for image acquisition when compared to adults, leading to the use of fewer radiographic views to evaluate these patients [1]. Thus, the purpose of this study was to systematically investigate the performance of different radiographic views in the identification of scaphoid fractures in children.

Materials and methods

Study group

Our study was approved by our Institutional Review Board (IRB) and performed in compliance with Health Insurance Portability and Accountability Act (HIPAA) regulations and with a waiver of written informed consent. A retrospective review of the imaging database (Nuance®; Montage Healthcare Solutions; Eden Prairie, MN, USA) for 4-view radiographic examinations of the wrist performed at our tertiary care children's hospital between January 1, 2008 and July 31, 2019, and on children and adolescents (defined as under 18 years of age) yielded an initial list of 490 consecutive patients. Patients with non-acute scaphoid fracture (> 6 weeks between injury and radiographic examination; $n = 36$) [22], syndromic or post-traumatic deformity ($n = 5$), a history of infectious or inflammatory arthropathy ($n = 2$), prior instrumentation ($n = 1$), no follow-up radiographic examinations ($n = 73$), or incomplete medical records ($n = 51$) were excluded. Radiographic diagnosis of a scaphoid fracture was established when a fracture cleavage plane or signs of healing (perifracture bony reabsorption or sclerosis) were visualized [16]. When available, computed tomography (CT) and MRI were also reviewed, and fractures were defined as cortical disruption that can be visualized on at least 2 orthogonal planes of imaging. Scaphoid injuries that were only conspicuous on follow-up radiographic examinations (as non-displaced, initially occult fractures), on CT (as subcortical micro-trabecular impaction), or on MRI (as bone marrow edema pattern reflecting contusion) were excluded ($n = 8$). The remaining 314 children with snuffbox tenderness consisted of 87 patients with and 227 patients without a scaphoid fracture. To ensure adequate statistical power of this study, the guidelines of Sim and Wright were used to determine the minimal sample size [23]. According to calculations, for a study to detect statistical significance ($p < 0.05$) with 80% power, assuming a one-tailed test and the null value = 0.00, 25 subjects would be required. Therefore, from the group with scaphoid fractures, a cohort of 29 patients was randomly selected and their corresponding age- and sex-matched controls were randomly selected from the non-fracture group.

Electronic medical records were reviewed to gather demographic data and information pertaining to the mechanism of injury, time between injury and radiographic examination, and patient outcome. At our institution, non-operative management with a splint or a cast is the preferred treatment for all suspected non-displaced scaphoid fractures, regardless of whether or not a discrete fracture is visible on the initial radiographic examination. Follow-up examinations are obtained at 2- to 6-week intervals, depending on the symptoms of the patient and the preference of the surgeon, to assess for signs of healing and detect complications. Surgical intervention is reserved for children with displaced fractures (> 1 mm) at presentation, those who have failed conservative management, or those who presented late (> 6 weeks after injury) with ongoing symptoms [6, 16].

Radiographic examinations

Wrist radiographs were performed using digital direct radiography (Luminos Agile; Siemens, Erlangen, Germany) according to our institutional preset imaging parameters in order to generate the best tissue contrast using the lowest possible radiation dose. Preset imaging parameters for children between 5 and 12 years of age are 50 kilovoltage (kV) and 1.25 milliampere-second (mAs), and for children over 12 years of age, the parameters are 52 kV and 1.25 mAs. A 4-view radiographic examination of the wrist includes posteroanterior (PA), oblique, lateral, and PA scaphoid views. Images are acquired with the patient in a sitting position and with his or her injured hand and wrist placed on the imaging table. The PA view is acquired with the hand and wrist placed in complete pronated position (palm-side down) on the imaging table. The oblique and lateral views are acquired with the hand and wrist placed in 45° and 90° semi-supinated positions, respectively. The PA scaphoid view is acquired with the wrist placed in ulnar deviation and with the X-ray beam angled 25° in the cephalad direction [24–26] (Fig. 1).

Image review

After randomization, each radiographic examination was retrospectively reviewed by a senior radiology technologist with 26 years of clinical experience and 3 board-certified pediatric physicians, all of whom were blinded to the fracture diagnosis. The senior technologist reviewed all images from each radiographic view and rated the positioning of the wrist on each image. An image was rated "good" if there was proper positioning of the wrist and "malpositioned" if there was improper wrist rotation or flexion. A radiologist with dual fellowship

Fig. 1 Four-view radiograph examination of the wrist for suspected scaphoid fracture. Posteroanterior (PA, **a**), oblique (**b**), lateral (**c**), and PA scaphoid (**d**) views of the right wrist from a 12-year-old boy, who suffered injury during sports 2 weeks prior to imaging, show a waist fracture of the scaphoid (arrows)

training in both pediatric and musculoskeletal radiology (8 years of clinical experience), another radiologist with fellowship training in pediatric radiology and sub-specialization in emergency radiology (8 years of clinical experience), and a surgeon with dual fellowship training in both pediatric and upper extremity orthopedic surgery (8 years of clinical experience) reviewed all images from each radiographic view, independent of the other views and other raters, to determine the presence or absence of a scaphoid fracture and recorded the fracture location when present. Disagreements in interpretation were settled by accepting the majority consensus as the final interpretation.

Each examination was independently reviewed 2 more times by the two radiologists with at least 1 week between each review, first using the 3-view examinations (which contained PA, oblique, and lateral views) and later using the 4-view examinations (which contained PA, oblique, lateral, and PA scaphoid views). Disagreements in interpretation were settled through a consensus review performed during a separate session to make the final interpretation.

When a scaphoid fracture was identified, the fracture pattern was subcategorized based on its anatomic location into distal corner, distal pole, waist, or proximal pole of the scaphoid. A distal corner fracture was defined as a fracture that involved less than two-thirds of the width of the distal scaphoid, which included avulsion and tubercle fractures. A fracture of the scaphoid body was defined as a fracture that involved more than two-thirds of the width of the scaphoid and was divided into those that involved the distal pole, waist, and proximal pole corresponding to distal, middle, or proximal thirds of the scaphoid [16].

Statistical analysis

Statistical analyses were performed using SPSS Statistics for Macintosh, version 26.0 (IBM Corp, Armonk, NY) with a two-tailed $p < 0.05$ considered statistically significant. Continuous variables were presented as means and standard deviations (SD) and categorical variables as counts and percentages. Student's t test was used to compare the means and chi-square the categorical variables. Percent agreement represents the percentage of cases where all raters agreed. Kappa (κ) statistics, either Fleiss's kappa (for 3 raters) or Cohen kappa (for 2 raters), were also used to calculate inter-rater agreement with absolute agreement and a two-way random effect model with 95% confidence interval (CI) to determine the presence of absence of a scaphoid fracture. Kappa statistics were categorized as follows: less than 0.20, slight agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; and greater than 0.81, almost perfect agreement [27]. Sensitivity and specificity with 95% CI, positive predictive value (PPV), and negative predictive value (NPV) were calculated for individual and multiple (3-view and 4-view) radiographic views.

Results

Patient information

The study group of 58 children (48 boys and 10 girls; mean age 13.1 ± 2.1 years; range 9–17 years) consisted of 29 children with acute scaphoid fractures and 29 age- and sex-matched children without fractures. The 29 scaphoid fractures included 8 distal corner, 9 distal pole, 10 waist, and 2 proximal pole fractures and the most common mechanism of injury was falling ($n = 21$), followed by sports ($n = 6$) and others ($n = 2$; wrist caught in a bike and punching). There was no significant difference in the mechanism of injury ($p = 0.17$), laterality ($p = 0.79$), or lag time between injury and radiographic examination ($p = 0.36$) between fracture and non-fracture groups. Duration of follow-up was significantly longer ($p = 0.01$) for the fracture group when compared to the non-fracture group, but no patient required surgical intervention.

Table 1 summarizes additional demographic data and information pertaining to wrist position. Overall, the PA view had the highest number of images that were rated "good" in wrist position ($n = 38$, 66%) while the PA scaphoid view had the lowest number ($n = 30$, 52%). No significant difference was found in the quality of the wrist position between fracture and non-fracture groups for PA ($p = 0.40$), oblique ($p = 0.28$), lateral ($p = 0.59$), and PA scaphoid views ($p = 0.18$).

Scaphoid fracture identification

Table 2 summarizes the percent agreement and kappa statistics for the identification of scaphoid fractures on various radiographic views. For multiple radiographic views, the 4-view examination had higher inter-rater agreement (93%; almost perfect agreement, $\kappa = 0.86$) when compared to the 3-view examination (86%; moderate agreement, $\kappa = 0.72$). For individual radiographic views, the PA view had the highest inter-rater agreement (81%; substantial agreement, $\kappa = 0.74$) while the lateral view had the lowest agreement (52%; slight agreement $\kappa = 0.19$).

Table 3 summarizes the sensitivity, specificity, PPV, and NPV of various radiographic views for the identification of pediatric scaphoid fractures. For multiple radiographic views, the 4-view examination had higher sensitivity (96.5%), specificity (96.5%), PPV (97%), and NPV (97%) when compared to the 3-view examination (93% for all tests). For individual radiographic views, the PA scaphoid view had the highest sensitivity (89.6%) and NPV (90%) (Fig. 2). The oblique view has the highest specificity and PPV (100% for both), but lacked sensitivity (55%). Specifically, the oblique view allowed the identification of only 6/8 (75%) corner, 5/9 (56%) distal pole, 4/10 (40%) waist, and 1/2 (50%) proximal pole fractures.

Discussion

Using a study cohort of 29 randomly selected radiographically conspicuous scaphoid fractures in pediatric patients, our study showed that fractures to the distal scaphoid were most common and were predominantly sustained from falls. The 4-view examination had higher diagnostic performance and inter-rater agreement for the identification of scaphoid fractures when compared to the 3-view examination. Individually, the PA scaphoid view had the highest sensitivity while the oblique view had 100% specificity for the identification of pediatric scaphoid fractures.

Fracture of the distal scaphoid (distal corner and distal pole) accounted for over half of acute fractures in our study cohort and injury from falling was the most common mechanism of injury. These findings are consistent with the published literature [1, 4, 5, 9–13]. The scaphoid ossification center forms around 5 years of age and reaches skeletal maturity around 13 years and 4 months in girls and 15 years and 9 months in boys [28]. In contrast to skeletally mature scaphoids where the waist is relatively weaker due to thinner and more sparse trabeculae [8], the site of weakness in skeletally immature scaphoid is in and around the osteochondral junction at its circumferentially and peripherally located growth plate, making it susceptible to injury from shear and traction forces. Preferential injury to the distal scaphoid in children is postulated to be the result of a combination of differential maturation (which progresses from a distal to a proximal direction) [6, 16, 18–20] and biomechanical demand as the distal scaphoid serves as the attachment site for the radioscaphoid ligament, the radial limb of the arcuate ligaments, and the radioscaphoid joint capsule [4, 8, 17].

Table 1 Demographic information between pediatric scaphoid fracture and non-fracture groups

Characteristics	Total (n=58)	Fracture (n=29)	No fracture (n=29)	p value
Age (years)	13.1±2.1	13.2 ±2.1	13.1±2.0	0.84
Sex Boys:girls	48:10	24:5	24:5	0.63
Laterality Right:left	29:29	14:15	15:14	0.79
Mechanism of injury				
Fall	35 (60)	21 (72)	14 (48)	0.17
Sports	17 (29)	6 (21)	11 (38)	
Others*	6 (11)	2 (7)	4 (14)	
Duration between injury and imaging (days)	2.6±5.1	3.3±6.4	2±3.4	0.36
Follow-up (days)	62.5±78.2	89.3±99.4	35.7±32.7	0.01
Wrist position (good)				
PA	38 (66)	17 (59)	21 (72)	0.40
Oblique	33 (57)	19 (66)	14 (48)	0.28
Lateral	35 (60)	16 (55)	19 (66)	0.59
PA scaphoid	30 (52)	12 (41)	18 (62)	0.18

Values are presented as number (percentage) or mean ± standard deviation

PA, posteroanterior

*Others included wrist caught in a bike (n = 1) and punching (n = 1) in the fracture group; punching (n = 2) and fighting (n = 2) in the non-fracture group

Radiographic examinations that contained multiple views (3-view and 4-view) outperformed individual views (PA, oblique, lateral, or PA scaphoid) in sensitivity and in inter-rater agreement for the identification of scaphoid fractures. Comparing between 3-view and 4-view examinations, the latter had higher sensitivity, specificity, and inter-rater agreement in our study, which suggests that the PA scaphoid view improved the diagnostic accuracy for the identification of pediatric acute scaphoid fracture despite age-dependent variability in fracture patterns. Although most authors recommend more than 2 radiographic views for the evaluation of clinically suspected scaphoid fractures, no guidelines exist on the optimal number of views (3-view, 4-view, or more) or which views should be obtained. While a variety of specialized wrist positions have been proposed, which include different finger positions (extended or flexed) and variable degree of wrist pronation, dorsiflexion, and ulnar deviation [4, 5, 7, 9, 13, 24–26], there is a relative paucity of descriptive information on the specific views used to establish the diagnosis of scaphoid fractures in the existing literature [1, 10, 29]. This lack of consensus and guideline may explain the widely variable reported sensitivity for the detection of acute scaphoid fractures in children ranging between 21% and 97% [6]. In our study, the highest sensitivity was achieved with the more comprehensive 4-view radiographic examination of the wrist, which also had near perfect inter-rater agreement.

Table 2 Percent and inter-rater agreements for pediatric scaphoid fracture identification

Views	Agreement	κ* (95% CI)
Multiple views (2 raters)		
3-view	86%	0.72 (0.47–0.98)
4-view	93%	0.86 (0.61–1.12)
Individual views (3 raters)		
PA	81%	0.74 (0.59–0.89)
Oblique	79%	0.66 (0.52–0.81)
Lateral	52%	0.19 (0.05–0.34)
PA scaphoid	59%	0.43 (0.28–0.58)

CI, confidence interval; *PA*, posteroanterior

*Cohen kappa was used for the calculation of agreement for multiple views (2 raters) and Fleiss's kappa for individual views (3 raters)

Our study also investigated the diagnostic performance of each radiographic view individually and found that the PA scaphoid view had the highest sensitivity and NPV for the identification of scaphoid fractures when compared to other views. The PA scaphoid view, acquired with the wrist placed in ulnar deviation and with angulation of the radiation beam, is often recommended as it provides a better profile of the scaphoid and reduces osseous overlap [7, 13, 25, 26]. However, this recommendation is derived from data originally gathered predominantly using adults and its diagnostic performance in children and adolescents has not been previously reported. Although optimal positioning of the wrist was most difficult with the PA scaphoid view, the results from our study support

Table 3 Sensitivity and specificity of different radiographic views for pediatric scaphoid fracture

Views	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Multiple views				
3-view	93.0 (75.7–98.7)	93.0 (75.7–98.7)	93	93
4-view	96.5 (80.3–99.8)	96.5 (80.3–99.8)	97	97
Individual views				
PA	82.7 (63.5–93.4)	96.5 (80.3–99.8)	96	84
Oblique	55.0 (35.9–73.0)	100 (85.4–100)	100	69
Lateral	41.0 (24.0–60.8)	93.0 (75.7–98.7)	85	61
PA scaphoid	89.6 (71.5–97.2)	93.0 (75.7–98.7)	92	90

Values are percentages with 95% CI in parentheses

CI, confidence interval; *NPV*, negative predictive value; *PA*, posteroanterior; *PPV*, positive predictive value

the claim that this view also improved the diagnostic accuracy for the identification of acute scaphoid fractures in pediatric patients.

The oblique view had the highest specificity for the detection of scaphoid fracture in our study cohort, but this view lacked sensitivity. The scaphoid in its neutral position is slightly tilted in the palmar direction and can appear foreshortened on the PA view [26]. However, semi-supination of the wrist (used to acquire the oblique view) provides a better profile of the distal scaphoid, which is particularly beneficial in children where fractures preferentially involve the distal pole and distal corner [4, 5, 25, 26]. The

Fig. 2 Example of a fracture that was best visualized on the PA scaphoid view. PA (**a**), oblique (**b**), lateral (**c**), and PA scaphoid (**d**) views of the left wrist from a 13-year-old male, who sustained a fall 1 day prior to imaging, show a non-displaced fracture through the waist of the scaphoid that is best visualized on the PA scaphoid view (arrows)

lower sensitivity of the oblique view may be due to the less optimal profiling of the proximal aspect of the scaphoid due to overlap with the other bones of the carpus, causing at least half of the fractures of the waist and proximal pole to be inconspicuous on the oblique view. The latter may also explain why the lateral view (with the greatest osseous overlap) had the lowest sensitivity in our study, a finding that is concordant with previously published results on adults [7].

Our study had several limitations. First, the retrospective design of our study prevented additional or repeat imaging and gathering of more clinical information. The inclusion of various ages and injury mechanisms introduced some heterogeneity to the study cohort, but stringent exclusion criteria were used to exclude any radiographic examinations that contained insufficient clinical or incomplete follow-up information to establish the presence or absence of a scaphoid fracture. This method was purposely selected as it better reflects routine clinical environment at most pediatric institutions [30, 31]. The presence of a fracture cleavage plane or signs of healing were used to establish the diagnosis of a scaphoid fracture, which may underestimate the true prevalence of scaphoid injury as bone contusion and micro-trabecular impaction injury (that are often conspicuous on MRI and CT) may not led to cortical disruption and thus remain inconspicuous on radiographs [21, 32]. However, as non-displaced scaphoid injuries are treated conservatively, the use of radiographs remains the preferred imaging modality for routine clinical screening and treatment decision-making. Another limitation is the relatively small sample size of our fracture group, which prevented the assessment of age-dependent distribution in fracture patterns. However, the purpose of our study was to systematically evaluate the diagnostic performance of different radiographic views, and thus our study was designed to include both fracture and non-fracture cases and only those who underwent 4-view radiographic examinations in an acute setting. The latter would not be a representative sample of all pediatric scaphoid fractures as the number of radiographic views obtained is dependent on the ordering provider and the delay in clinical presentation is not uncommon in children. Although fractures are more conspicuous over time due to the accumulative healing response, we purposely limited our investigation to acute fractures where timely and accurate diagnosis can positively impact treatment decisions.

In conclusion, the 4-view radiographic examination of the wrist had the highest sensitivity with near perfect inter-rater agreement for the identification of various pediatric acute scaphoid fractures. The addition of the PA scaphoid view to the 3-view examination produced improved sensitivity and specificity while the PA scaphoid view alone had the highest sensitivity for the identification of a scaphoid fracture. This view is important even though optimal positioning was only achieved for a little over half of the patients in our study cohort. Future studies that include a larger number of subjects are needed to further investigate the presence or absence of an association between fracture location and its visibility on different radiographic views, which may be particularly helpful in younger children where the acquisition of all 4 views can be challenging.

Code availability Not applicable

Authors' contributions Conceptualization—JCN, ASS, MKN, AG, SLK
Methodology—JCN, ASS, MKN, SB, AN, AG, SLK
Formal analysis and investigation—JCN, ASS, MKN, SB, AN, AG, SLK
Writing—original draft preparation—JCN, SB, AG
Writing—reviewing and editing—JCN, ASS, MKN, SB, AN, AG, SLK
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Supervision—JCN

Data availability All data were gathered from our institution and can be made available for review.

Compliance with ethical standards

Conflict of interest No relevant conflict of interest. Jie C. Nguyen received research grant support from the Radiologic Society of North America (RSNA) and the Children's Cancer Research Fund (CCRF), which is unrelated to the current project.

Ethical approval 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.

Consent to participate Ethical approval was waived by the local Ethics Committee of the Children's Hospital of Philadelphia in view of the retrospective nature of the study and all the procedures being performed were part of the routine care.

Consent for publication Authors consent and this material has not been published elsewhere.

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