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● *Original Contribution*

POINT-OF-CARE ULTRASOUND FRACTURE–PHYSIS DISTANCE ASSOCIATION WITH SALTER–HARRIS II FRACTURES OF THE DISTAL RADIUS IN CHILDREN: THE "POCUS 1-CM RULE"

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Abstract—Salter–Harris II fractures of the distal radius can result in serious complications. The aim of this study was to measure the fracture–physis distance using point-of-care ultrasound (POCUS) to determine whether a certain distance is associated with Salter–Harris II fractures, compared with other fracture types, in a cohort of children with X-ray–identified distal radius fractures. Participants were from a parent diagnostic study conducted in an Australian tertiary pediatric emergency department, which prospectively evaluated the diagnosis of pediatric distal forearm fractures using POCUS compared against X-ray. Nurse practitioners, who underwent 2 h of training, administered a six-view POCUS protocol in clinically non-angulated pediatric forearm injuries prior to X-ray. This was a secondary analysis of data from the parent study. The 122 participants with X-ray–identified distal radius fractures from the parent study had their POCUS images interpreted by two emergency physician sonologists, who measured the fracture–physis distance. The median and maximum fracture–physis distances for Salter–Harris II fractures (n = 19) were 8.00 and 9.85 mm, whereas minimum and median distances for incomplete fractures (n = 22) were 10.20 and 15.98 mm, and those for complete fractures (n = 9) were 10.85 and 12.85 mm. Buckle fracture (n = 72) distances ranged from 4.35 to 26.55 mm, with a median of 13.65 mm. In children diagnosed with a distal radius fracture on X-ray, a fracture–physis distance cutoff of 1 cm differentiated Salter–Harris II fractures from other cortical breach fracture types, but not buckle fractures. Although this exploratory study suggests the "POCUS 1-cm rule" could be used as a secondary sign to augment the diagnosis of Salter–Harris II distal radius fractures using POCUS, further research is required to validate this measurement prospectively. (E-mail: peter.j.snelling@gmail.com)

Key Words: **Buckle (torus), Distal forearm, Fractures, Pediatric, Point-of-care ultrasound, Ultrasonography, Radius, Salter–Harris.**

INTRODUCTION

Pediatric distal forearm fractures are common, with the highest incidence of fracture in late childhood and early adolescence (Rennie et al. 2007; Stutz and Mencio 2010). Children aged less than 12 y will generally sustain buckle (torus) fractures of the distal radius metaphysis, whereas physeal fractures occur more often in the adolescent age group, typically because of strengthening bone compared with the weaker cartilaginous physis (Kramhoft and Bodtker 1988; Larsen et al. 2016). Salter–Harris II fractures of the distal radius are by far the most common physeal fracture in children (Mann and Rajmaira 1990; Larsen et al. 2016). The diagnosis of Salter–Harris II fractures of the distal radius is essential as they involve the physis and could potentially displace and, on rare occasions, cause significant complications such as growth arrest (Cannata et al. 2003; Larsen et al. 2016).

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The current pragmatic reference standard to diagnose a distal forearm fracture is two-view X-rays (radiography) of the forearm or wrist, reported by a radiologist (Metz and Gilula 1993). X-Rays have historically been used for the initial screening and diagnosis of fractures as they are generally available and universally interpreted. Point-of-care ultrasound (POCUS) is an alternative non-ionizing imaging modality that can be used to diagnose fractures in distal forearm injuries in children (Douma-den Hamer et al. 2016; Snelling et al. 2021a). POCUS could potentially negate the requirement for X-ray imaging in patients with either no fracture or a buckle fracture (Snelling 2020; Snelling et al. 2021a). However, the risk of using POCUS in this way would be missing potentially clinically important fractures, such as Salter−Harris II fractures of the distal radius, which could lead to adverse outcomes if inappropriately managed (Larsen et al. 2016). It may be possible to determine the presence of distal radius Salter−Harris II fractures with a measurement using POCUS imaging, with the hypothesis that fractures closer to the metaphysis have a greater propensity to involve the physis. Such a measurement could assist as a means of improving the detection of Salter−Harris II fractures using POCUS.

The aim of this study was to determine whether POCUS-measured fracture−physis distance could be used to distinguish Salter−Harris II distal radius fractures from other fracture types in a cohort of children with X-ray−identified distal radius fracture.

METHODS

Study design and materials

This subsidiary study retrospectively analyzed data collected from a parent diagnostic study, which prospectively evaluated the diagnosis of pediatric distal forearm fractures using POCUS compared against X-ray. (Snelling et al. 2021a). The parent study was conducted at Queensland Children's Hospital, a large tertiary pediatric center in Southeast Queensland, Australia, between February 2018 and April 2019 (Snelling et al. 2021a). The Children's Health Queensland Hospital and Health Service Human Research Ethics Committee approved the study (HREC/17/QRCH/239). Written consent was obtained for all minors from their legal guardian prior to enrollment.

Participants

Patients were eligible for the parent study if they were aged 4 to 16 y, presented to the emergency department between 7 AM and 10 PM, with an isolated, clinically non-angulated distal forearm injury that required further evaluation with X-ray imaging, and a nurse practitioner (NP) trained in forearm POCUS was available to scan. The ultrasound-naïve NPs underwent a 2-h didactic training course consisting of a stage learning package with lectures combined with practical scanning, followed by three proctored scans on patients (Snelling 2018; Snelling et al. 2022a). Patients were not included if their injury was older than 1 wk at presentation, external imaging had already been performed or there was known bone disease; suspicion of non-accidental injury; congenital bone malformation; open fracture; neurovascular compromise; or distracting injury or suspicion for another fracture (*e.g.,* scaphoid or elbow).

In the parent study, potential participants were screened on presentation to the Emergency Department (ED), and consent forms were completed. All participants then underwent a POCUS examination (HFL50xp/15-6MHz, Fujifilm Sonosite Xporte, Bothell, Washington, USA) conducted by an NP followed by an X-ray conducted by a radiographer, subsequently reported by a radiologist. NPs scanned participants using a six-view POCUS protocol (Snelling et al. 2021a). Participants were included in this subsidiary study if they were diagnosed with a distal radius fracture on X-ray and had a fracture identified on the corresponding POCUS images that could be measured.

Outcome measures

All distal radius fractures diagnosed using X-ray were identified from the parent study. X-ray images were classified as Salter−Harris II, incomplete, complete or buckle fractures based on the radiologist report. No other Salter−Harris fracture subtypes were identified on X-ray imaging. In this subsidiary study, for each identified fracture, the corresponding POCUS images were independently measured by two emergency physician sonologists masked to X-ray diagnosis. The distance from the proximal portion of the fracture to the most proximal portion of the physis was recorded, using the shortest distance of either the dorsal, lateral or volar aspect, along the cortex of the metaphysis (Fig. 1). For each participant, the mean value of these two sonologist measurements was defined as the fracture−physis distance. Demographic and clinical characteristics of participants were collected from parent questionnaires and extracted from medical records.

Data analysis

Demographic features of participants by fracture type, including age, sex and affected side, along with analgesia received and initial POCUS diagnosis, were described using mean and standard deviation for continuous data or number and percentage for categorial data. The fracture−physis distance by fracture type was described using median, interquartile range minimum and maximum. A receiver operating characteristic

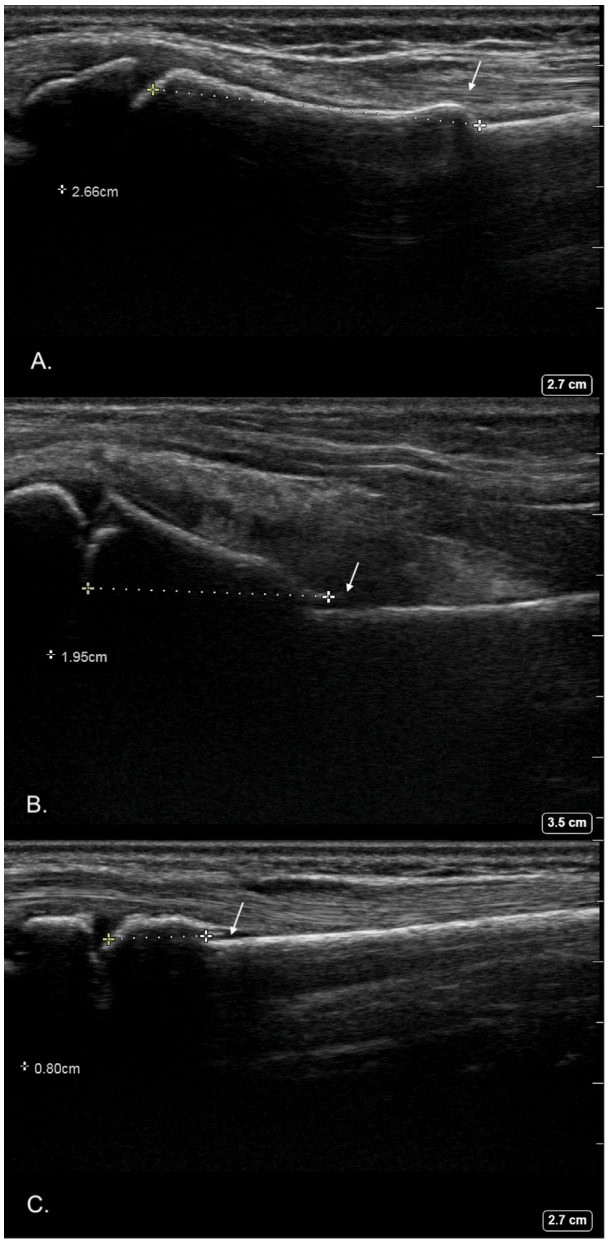

Fig. 1. Point-of-care ultrasound (POCUS) images revealing the fracture−physis distance measurement for a buckle fracture (A), an incomplete fracture (B) and a Salter−Harris II fracture (C).

(ROC) curve was used to identify the optimal cutoff value of fracture−physis distance for determination of Salter−Harris II fractures compared with all other fractures, defined as the point at which Youden's index was maximized. The area under the ROC curve (AUC) was calculated using the trapezoidal method, with the standard error of the AUC calculated using non-parametric methods and 95% confidence interval (CI) calculated assuming a normal distribution (DeLong et al. 1988). The proportion of each fracture type with a fracture−physis distance below the identified cutoff value was reported, with the 95% CI calculated using the Wilson method. All statistical calculations were performed using Stata/IC v14 (StataCorp, College Station, TX, USA).

RESULTS

Two-hundred and four participants were recruited in the parent study, with 129 having a forearm fracture on X-ray. Seven fractures were excluded from analysis: a bowing fracture of the radius, a possible non-displaced Salter−Harris III fracture of the distal radius (not seen on repeat X-ray imaging), three proximal two-thirds radius fractures, an isolated ulna styloid fracture and a Salter−Harris II radius fracture not identified on POCUS. Of the 122 analyzed X-ray−diagnosed fractures, 19 were Salter−Harris II fractures, 22 were incomplete fractures, 9 were complete fractures and 72 were buckle fractures (Fig. 2). Participant characteristics by fracture type are outlined in Table 1.

Emergency physician sonologist measurements of fracture−physis distance exhibited good agreement for each participant, with a mean absolute difference of 0.6 mm and 95% of measurements within ±1.6 mm.

Salter−Harris II fractures had a maximum fracture−physis distance of 9.85 mm, median of 8.00 mm and interquartile range (IQR) of 6.85−9.00 mm (Table 2, Fig. 3). In comparison the minimum fracture−physis distances for incomplete and complete cortical breach fractures were 10.20 and 10.85 mm, respectively, with a median (IQR) of 16.98 mm (14.25−19.35 mm) and 12.85 mm (12.00−20.40mm). Fracture−physis distances for buckle fractures ranged from 4.35 to 26.55 mm, with a median (IQR) of 13.65 mm (9.40−16.73 mm).

The optimal cutoff for Salter−Harris II fracture was identified as 9.85 mm (Fig. 4). The AUC was 0.88 (95% confidence interval [CI]: 0.82−0.94). All Salter−Harris II fractures were <9.85 mm, whereas 81 of 103 participants with other fracture types had fracture−physis distances >9.85 mm (79%, 95% CI: 70%−85%), including 51 of 72 patients with buckle fractures (71%, 95% CI: 59%−80%). At a practical cutoff of 10 mm, or 1 cm, all participants with Salter−Harris II fractures had a

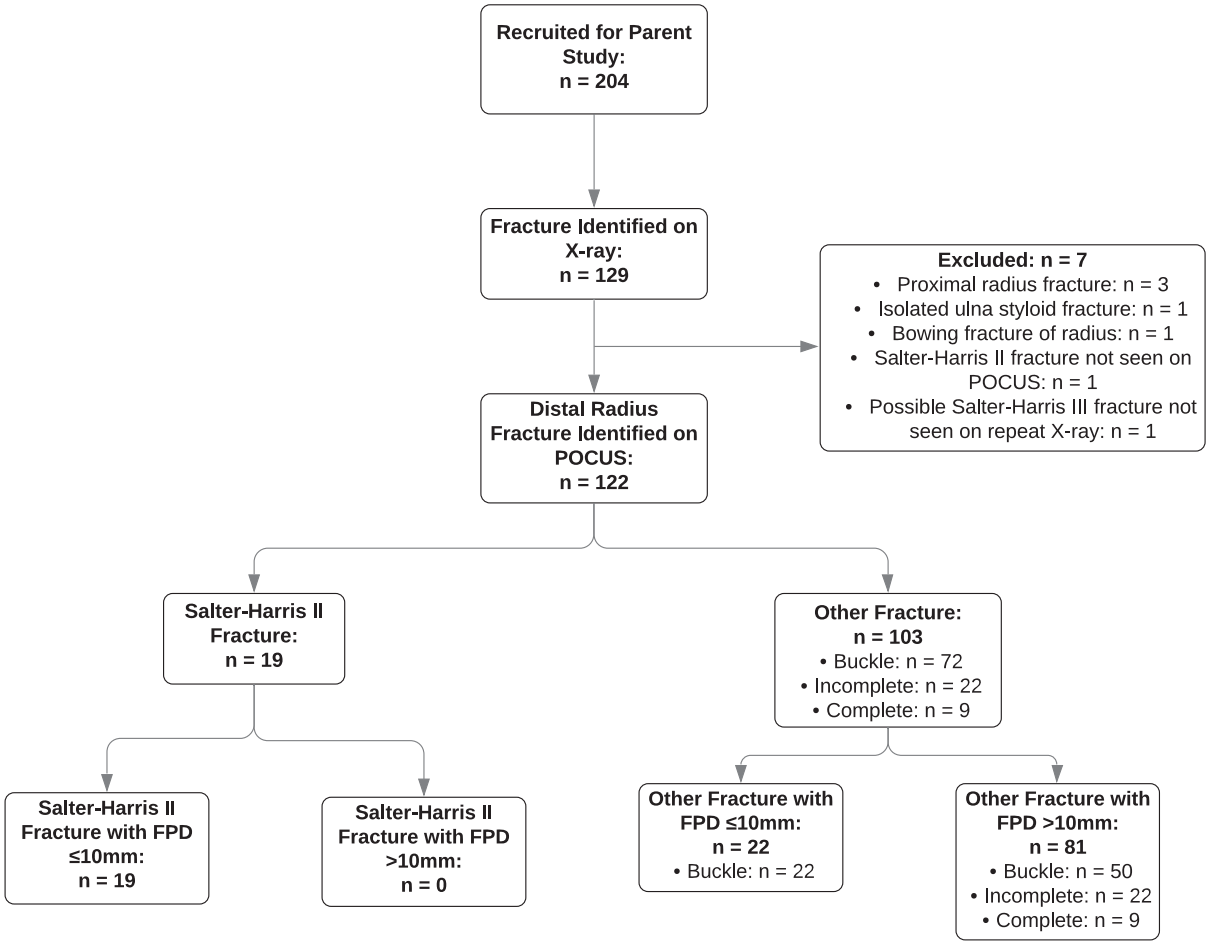

Fig. 2. Patient flow diagram. POCUS = point-of-care ultrasound; FPD = fracture−physis distance.

Table 1. Participant characteristics by fracture type (n = 122)

Characteristic	Salter–Harris II fractures (n = 19)	Incomplete fractures (n = 22)	Complete fractures (n = 9)	Buckle fractures (n = 72)
Age (y)	9.6 ± 2.8	8.2 ± 2.5	11.2 ± 2.9	9.0 ± 2.9
Sex				
Male	8 (42)	16 (73)	5 (56)	40 (56)
Female	11 (58)	6 (27)	4 (44)	32 (44)
Side				
Right arm	4 (21)	10 (45)	1 (11)	29 (40)
Left arm	15 (79)	12 (55)	8 (89)	43 (60)
Analgesia received				
No analgesia	2 (11)	4 (18)	0 (0)	18 (25)
Paracetamol and/or ibuprofen	15 (79)	16 (73)	8 (89)	54 (75)
Opioid analgesia	2 (11)	2 (9)	1 (11)	0 (0)

Results are expressed as the mean ± standard deviation or number (%) for patients with that fracture type.

Table 2. Summary statistics of fracture–physis distance (mm) by fracture type

Fracture type	n	Minimum	Percentile			Maximum	Distance, n (%)	
			25th	50th	75th		<10 mm	>10 mm
Salter–Harris II	19	3.55	6.85	8.00	9.00	9.85	19 (100%)	0 (0%)
Incomplete	22	10.20	14.25	15.98	19.35	28.10	0 (0%)	22 (100%)
Complete	9	10.85	12.00	12.85	20.40	35.95	0 (0%)	9 (100%)
Buckle	72	4.35	9.40	13.65	16.73	26.55	22 (31%)	50 (69%)

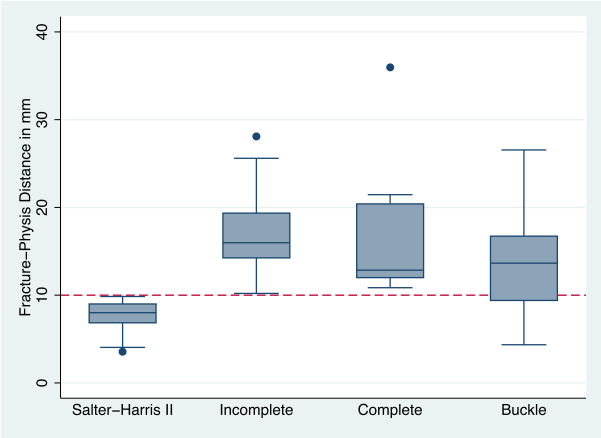

Fig. 3. Fracture–physis distance by fracture type.

fracture–physis distance ≤1 cm (19/19, 100%, 95% CI: 83%–100%), whereas 22 of 22 incomplete (1000%, 95% CI: 85%–100%), 9 of 9 complete (100%, 95% CI: 70%-100%) and 50 of 72 buckle (69%, 95% CI: 58%–79%) fractures had a fracture–physis distance >1 cm.

DISCUSSION

The POCUS-measured fracture–physis distance of 1 cm had good discriminatory value for Salter–Harris II fractures of the distal radius in a cohort of patients with X-ray–identified fracture. No incomplete or complete fracture had a fracture–physis distance <10 mm, whereas all Salter–Harris II fractures were <10 mm. However, this fracture–physis cutoff value did not discriminate buckle fractures, with approximately one-third of these having a distance <10 mm. Although POCUS has been determined to identify buckle and breaches of the cortex in children, the association between fracture–physis distance measured using POCUS and fracture type has not been previously described.

An X-ray–based "1-cm rule" has been proposed by Iles et al. (2019) to differentiate buckle fractures from

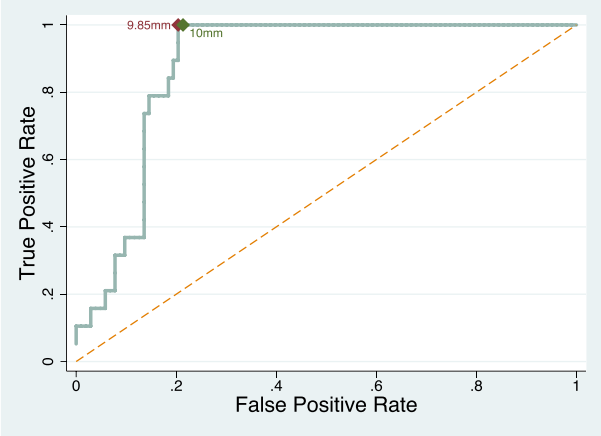

Fig. 4. Receiver operating characteristic curve for diagnosis of Salter–Harris II fracture by fracture–physis distance.

other fracture types. In a prospective cohort of 203 American children with confirmed distal radius fracture on X-ray, only 2 of 148 participants had a buckle fracture within 1 cm of the physis, measured as a distance extending from the proximal edge of the distal radius cortical deformity to the mid-distal radius physis. Their conclusion was that a fracture is unlikely to be a buckle fracture if the fracture-to-physis distance is <1 cm.

Although our POCUS measurements, albeit slightly different in technique, also identified 1 cm as an important cutoff, we found it distinguished Salter–Harris II fractures from other types of cortical breach fractures (*i.e.,* incomplete and complete fractures). We found a number of participants with buckle fractures who had a fracture–physis distance <1 cm. This difference may be due to the classification of "Salter–Harris II variant" fractures, otherwise known as a Peterson Type 1 fracture (Laor and Cornwall 2020). This fracture is a buckle fracture of the distal radius metaphysis with a microtrabecular fracture extending toward the physeal region, without discernible breach of the bone cortex on X-ray. However, these tend not to truly involve cleavage of the physis and can be managed in keeping with a buckle fracture entity in a splint, rather than with plaster immobilization (Boutis et al. 2010). These are logically a precursor to the formation of a true Salter–Harris II fracture, which result from further strain and can then become unstable. However, this was outside the scope of this study, so we did not analyze our cohort of buckle fractures to identify Salter–Harris II variants to test this hypothesis.

The standard POCUS protocol for forearm injuries involves scanning six views of the forearm, whereby the distal radius and ulna are interrogated on their dorsal, lateral and volar aspects with a high-frequency linear probe in a longitudinal axis with the probe marker oriented distally (Snelling et al. 2021a) . On ultrasound imaging, the bone cortex appears as a bright white echogenic line with posterior shadowing, given that the bone mostly blocks transmission and reflects the sound waves back to the transducer (Snelling 2020). Typically, fractures are identified with POCUS by the detection of either buckling (buckle fracture) or a breach in the cortex (incomplete, complete, Salter–Harris fractures). Whilst POCUS may identify a fracture line extending into the physis, this can often be difficult to visualize because of the posterior shadowing artifact, hence the attraction in using the POCUS fracture–physis distance as a predictor of physeal involvement in the presence of a cortical breach fracture.

When using POCUS to prospectively diagnose cortical breach type fractures, additional secondary signs can be utilized to increase the diagnostic yield of clinically important fractures, for example, a periosteal hematoma or the pronator quadratus hematoma sign (Snelling et al. 2021b, 2022b). The fracture–physis distance measured on POCUS imaging may be used as a secondary sign to assist the identification of Salter–Harris II fractures of the distal radius, indicating that the operator should be vigilant for a Salter–Harris II fracture when a buckling of the cortex is detected within 10 mm of the physis. Additionally, it may help differentiate Salter–Harris II fractures from other cortical breach fractures that do not involve the physis, as all other cortical breach fractures in this sample had fracture–physis distances >10 mm. However, the specificity of the fracture–physis measurement was reduced by buckle fractures close to the physis, which likely included Salter–Harris II variants.

Strengths of the study described here include the description of the novel fracture–physis measurement using POCUS on a cohort of children with X-

ray−identified distal radius fracture, with every patient who met the inclusion criteria enrolled. Additionally, two expert sonologist measurements were in good agreement, with both masked to the X-ray diagnosis. Limitations of the study include its being a retrospective analysis of a cohort from a single-center diagnostic study, which used NPs who were initially novice to POCUS. Although X-ray was used as the pragmatic reference standard in the parent diagnostic study, it may still miss occult Salter−Harris II fractures, which may have been identified on POCUS, repeat X-ray imaging or other imaging modalities such as magnetic resonance imaging (Elvey et al. 2016).

CONCLUSIONS

In children diagnosed with a distal radius fracture on X-ray, all Salter−Harris II fractures had a fracture−physis distance <10 mm on POCUS imaging, while all complete and incomplete fractures had a distance >10 mm. This cutoff distance in itself did not differentiate Salter−Harris II fractures from buckle fractures. The POCUS-measured fracture−physis distance, the "POCUS 1-cm rule," has potential to prospectively identify Salter−Harris II fractures when children present to the emergency department. Further research in a prospectively collected cohort is required to assess the diagnostic accuracy of this measurement.

DATA AVAILABILITY STATEMENT

Data are available upon reasonable request.

CONFLICT OF INTEREST DISCLOSURE

The authors declare no competing interests.

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