Hand Surgery and Rehabilitation 43 (2024) 101755

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Original article

Ultrasound-based Measurement of the Intra-scaphoid angle

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A R T I C L E I N F O

Article history:
Received 24 June 2024
Received in revised form 22 July 2024
Accepted 23 July 2024
Available online 6 August 2024

Keywords:
Sonographic measurement
Ultrasound
Scaphoid fracture
Scaphoid
Scaphoid non-union
Humpback deformity
Diagnostic accuracy

A B S T R A C T

Introduction: Ultrasound is gaining popularity for diagnosing scaphoid fractures. However, it hasn't been used to assess fracture displacement, such as humpback deformity. We propose a sonographic method to measure the intra-scaphoid angle, potentially serving as an alternative to CT scans for detecting fragment malposition after a scaphoid fracture.

Methods: We recruited 11 healthy adult volunteers without wrist pathology and performed bilateral wrist ultrasounds, totaling 22 examinations. Each wrist was splinted at 50° extension and fully supinated. Two hand surgeons independently performed the ultrasounds. All images were then evaluated separately by two evaluators. The following measurements were taken: 1. Inter-poles distance (IPD): Distance between the summits of the two scaphoid poles on the palmar cortex. 2. Palmar cortical intra-scaphoid angle (PCISA): Angle between the two summits and the deepest point of the waist on the palmar cortex. Measurements were compared for inter-investigator and inter-evaluator reliability using the intraclass correlation coefficient (ICC).

Results: The study included four males and seven females, with an average age of 35 years (range 21–56). The mean PCISA was 142° (SD 10°) and the mean IPD was 16.3 mm (SD 2.1 mm). Differences in IPD measurements averaged 0.3 mm (range 0–5.2 mm) among investigators and 1.0 mm (range 0.1–3.8 mm) among evaluators. For PCISA, the differences averaged 4° (range $0–17^{\circ}$) among investigators and 6° (range $0–15^{\circ}$) among evaluators. The ICC for IPD was 0.804 (investigators) and 0.572 (evaluators); for PCISA, it was 0.704 (investigators) and 0.602 (evaluators).

Conclusion: This study presents a cost-effective and accessible sonographic technique to measure the intra-scaphoid angle. Further research is required to assess its effectiveness in scaphoid fractures and compare it to CT-based measurements like the H/L ratio, LISA, and DCA.

1. Introduction

Scaphoid fractures are the most common carpal bone fractures, especially in young men, often caused by a fall on an outstretched hand or sudden forced dorsiflexion of the wrist [1]. Most scaphoid fractures heal in a below-elbow plaster cast, but displaced fractures have a higher risk of nonunion [1–4].

In middle-third scaphoid fractures, the distal pole often tilts palmarly, and the proximal pole extends dorsally with the lunate due to the intact scapholunate (SL) ligament [5], potentially resulting in a "humpback deformity" if the fracture heals in this position [6].

Displacement rates vary widely depending on the radiological methods and criteria of displacement used, with radiographs alone showing about a 20% displacement rate [1,7].

Malunion occurs in a significant percentage of fractures (62%) as judged by CT, suggesting a high rate of initial or healing-related displacement [8].

The scaphoid participates in the wrist's proximal and distal rows. Malunion can disrupt delicate balance of the wrist and therefore their biomechanics, causing pain, weakness, and limited motion, potentially leading to degenerative changes [6,9].

Accurate assessment of scaphoid displacement is crucial for proper treatment. However, evaluating its complex three-dimensional shape is challenging. The initially used trispiral tomograms is unreliable to assess malunion [2,10], and while CT scans are commonly used to assess scaphoid form and union by several different parameters, including the lateral intrascaphoid angle

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https://doi.org/10.1016/j.hansur.2024.101755

(LISA), the dorsal cortical angle (DCA) and the height-to-length (H/L) ratio [10–12], they have limited reproducibility [8,10,11] and involve high radiation exposure, a limited availability [13] and that it is difficult to use intraoperative.

Through constant advancement, ultrasound (US) has become a reliable, non-invasive, and cost-effective diagnostic tool, increasingly used in hand surgery [13–15].

Under others in the diagnose of scaphoid fractures. It effectively visualizes cortical bone, making it useful for identifying scaphoid fractures as small as 1 mm with high specificity [16].

However, US has not been used to assess fragment displacement so far. A lack of a reliable technique may be the reason.

In our department we developed a new technique to measure the scaphoid fragment displacement based on three anatomical points on the palmar cortical scaphoid. This technique's reliability and reproducibility are still unproven. Our study aims to evaluate the interobserver reliability of this sonographic measurement in a healthy population. If successful, this method could improve preoperative planning and bone reconstruction, potentially replacing CT scans, reducing patient radiation exposure, and lowering healthcare costs.

2. Material and methods

A prospective study was conducted at the University Hospital of Lausanne - Centre Hospitalier Universitaire Vaudois (CHUV), complying with the 1964 Helsinki declaration and was approved by the local ethical boards (CER-VD 2022-01506).

We recruited 11 adult, healthy volunteers without any wrist pathology. Informed consent was obtained from the participants. General parameters were collected including sex and age. No patient with a prior wrist trauma or wrist surgery were admitted to the study. In this study population a bilateral wrist ultrasound was performed (adding to 22 measurements) and the two below described parameters (inter-poles distance [IPD] and palmar cortical intra-scaphoid angle [PCISA]) were measured by two investigators independently (MM, BM). Independent measurements of the angles by the different investigators, assured an unbiased collection of the measurements. In addition, the bilateral wrist images and measurements of a patient with a known humpback deformity have been collected and are included as a case example of a pathologic measurement.

2.1. Sonographic examination

A US of both wrists was performed from the palmar side in full supination and 50 ° dorsal extension. This allowed to standardize the wrist position during the exam and to bring the scaphoid in extension, assuring a good visualization of both poles and the waist of it.

Fig. 1. Positioning of a left wrist for standardized measurement acquisition in a custom-made splint in full supination and 50 ° of extension. Note the position of the sonographic probe marked with a red line.

This position was lined out in prior pilot studies, were in a few cases (3 volunteers not included in the final study), the best position was assessed for the visualization of the scaphoid (including different degrees of extension and ulnar deviation).

The wrist position was maintained with a custom-made synthetic plaster, fixed with a strip at the forearm and the hand (Fig. 1).

US is performed by two different investigators, all two hand surgeons with training in US of the hand. Both were especially trained to outline the scaphoid in the mentioned pilot study.

Examinations were performed on an Aixplorer™ ultrasound system (Supersonic Imagine, Aix-en-Provence, France). A high-resolution 5–18 MHz linear array transducer (SuperLinear™ SL18-5; Supersonic Imagine, Aix-en-Provence, France) with 256 elements and a bandwidth from 5 to 18 MHz was used. The examination took place in the dedicated room for sonography with the participant sitting in front of the investigator with the examined hand resting on the examination table.

The examination is made through standard transmission sonographic gel. The pre-programmed settings for wrist sonography on the Aixplorer ultrasound system were used concerning gain and power and manually adapted if necessary. The sonographic probe was placed in a slightly oblique fashion of the longitudinal forearm axes, in line with the longitudinal axis of the scaphoid using some palpable surface landmarks (distal pole of the scaphoid, wrist flexion creases, thumb axis) (Fig. 1).

Using sonographic anatomic landmarks of the wrist and starting the examination from the radius, the scaphoid is identified by its bilobed or peanut-shape, with a smooth and hyperechoic bone surface contour (Fig. 2). The depth was then centred on the waist of the scaphoid and the probe was then moved in a fanlike fashion to obtain the best image, showing both poles and the

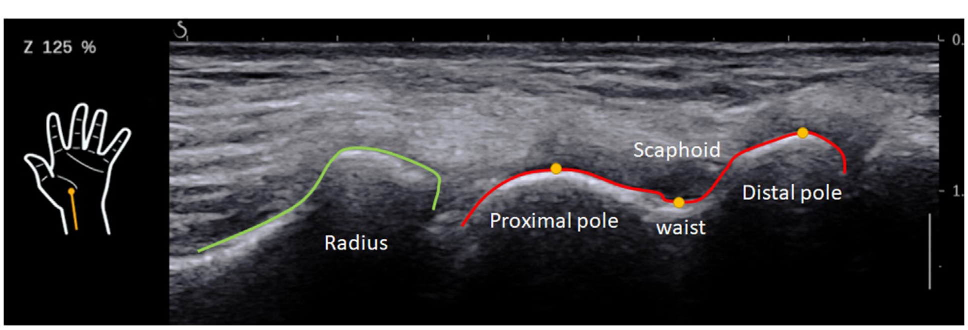

Fig. 2. Ultrasound image of a left wrist, showing the used anatomical landmarks. The surface of the radius (green), and scaphoid (red) are outlined. Yellows dots mark the three points used for the sonographic measurements on the scaphoid poles and the scaphoid waist.

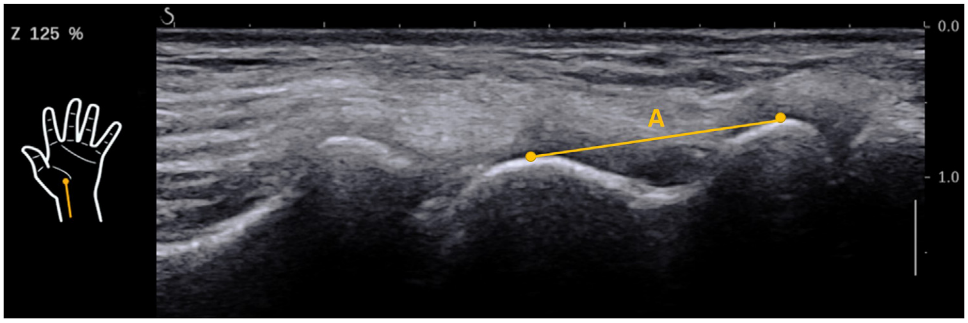

Fig. 3. Ultrasound image of the same left wrist as in Fig. 2, with the inter-pole distance (IPD) marked (yellow and labeled with A).

scaphoid waist. This image was then frozen with the competent button. Our US machine allow to scroll back in time once an image is frozen to "fine-tune" the choice of the best image. Images were then saved in the picture archiving and communication system (PACS).

Examination of both wrists is performed systematically in all participants.

2.2. Evaluation of the images

The images obtained were then evaluated by the same investigators independently on the PACS. In clinical practice, the measurements can also be taken after the acquirement of the images on the US machine without affecting the results, however in our study we decided to do it on the PACS, to allow repeated and blinded measurements. To differentiate between the person performing the US (investigator), in the further text, we will use the term evaluator, for the person evaluating the image.

Every evaluator evaluated not only the image he or she took as an investigator, but also the images of the other investigator separately (adding to 44 evaluation of the parameters).

2.3. Sonographic measurements

Following the acquisition of the images, two new described parameters were then measured:

First, the inter-poles distance (IPD): defined as the distance between the summit of the two scaphoid poles (Fig. 3). The summit of the pole was defined as the point lying on the respective pole, farest away from the scaphoid waist in a distance perpendicular to the axis of the scaphoid.

Second, the palmar cortical intra-scaphoid angle (PCISA): representing the angle between these two above mentioned points on the poles and an additional point on the deepest point of the scaphoid waist in regard of the corresponding axis of the scaphoid (Fig. 4).

2.4. Statistical analysis

We based our sample choice on similar studies and on our before mentioned pilot study in which the SD (3.1 °) of the measurements of the PCISA on 3 volunteers was used. The $\acute{\alpha}$ was set to 0.05 and the β of 0.80. The effect size was set at 5 °, that we jugged a measurable difference of an angle, the resulting required sample size was 3.01. As other similar studies used around 20–30 cases [13,14,17,18] we decided to have 22 measurements for this feasibility study, to be in this range and clearly exceed the 3 measurements needed of our sample size calculation. All these measurements finally adds to 44 evaluations exceeding also the forementioned range of other studies. The measurements are then compared for the inter-examiner and inter-observer reliability using an intraclass correlation coefficient (ICC) with 95% confidence interval (95% CI). The resulting ICC is then classified according two different commonly used systems [19,20]. The difference between the two contralateral sides in this population was also calculated in between the same measurements (same investigator and evaluator).

3. Results

The study included eleven healthy volunteers, consisting of four males and seven females. The average age of the participants was 35 years, with a median age of 30 years (ranging from 21 to 56 years). The mean PCISA across all measurements was 142 ° (SD 10 °) and the IPD was 16.3 mm (SD 2.1 mm) (Fig. 5).

Among different investigators, the mean difference in IPD measurements was 0.3 mm (ranging from 0 to 5.2 mm) and for PCISA, it was 4 ° (range 0–17 °). Among different image evaluators, the mean difference in IPD measurements was 1.0 mm (range 0.1–3.8 mm) and for PCISA, it was 6 ° (range 0–15 °).

The ICC between the two investigators was 0.804 for the IPD and 0.704 for the PCISA. The ICC between the two evaluators was 0.572 for the IPD and 0.602 for the PCISA.

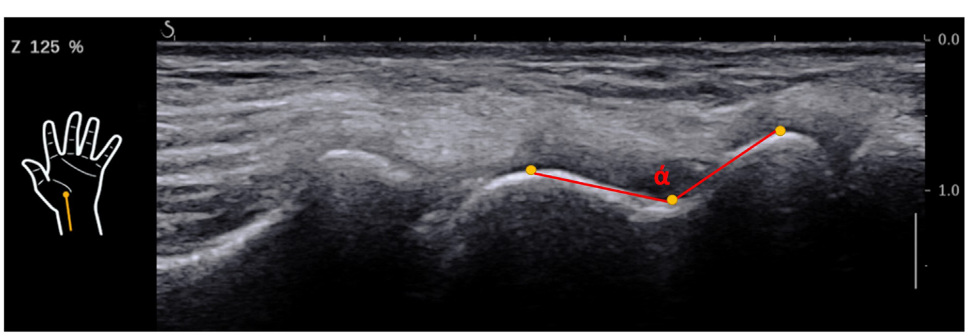

Fig. 4. Ultrasound image of the same left wrist as in Figs. 2 and 3, with the palmar cortical intra scaphoid angle (PCISA) marked (red and labeled with $\acute{\alpha}$).

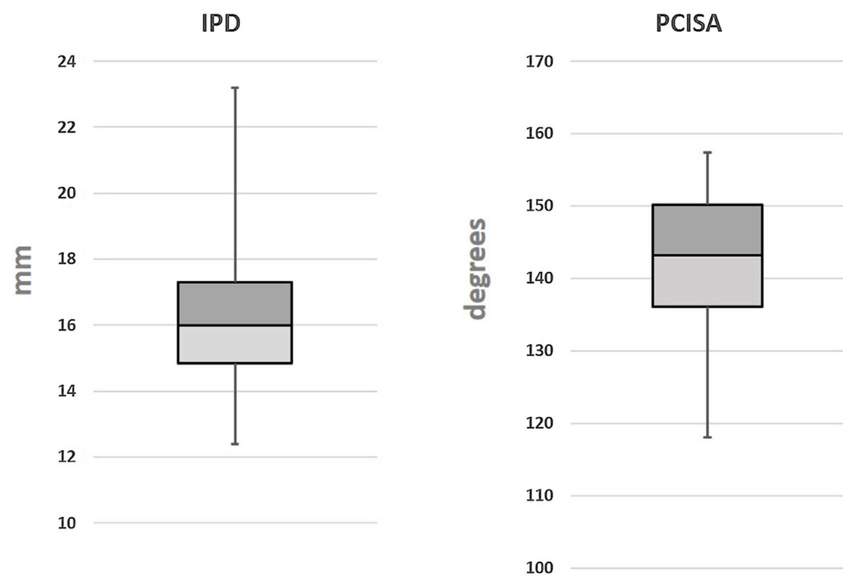

Fig. 5. Boxplot Diagram of the inter-pole distance (IPD) in millimeter (mm) and of the palmar cortical intra scaphoid angle (PCISA) in degrees in our cohort.

The difference of the measurements between the two contralateral sides was of average 1,0 mm (range 0–5.3 mm) for the IPD and 3.6 ° (range 0.1–13.4) for the PCISA.

4. Discussion

We introduced a new sonographic technique with two parameters to assess scaphoid alignment. This study tested the technique's reliability in a healthy population, focusing on image acquisition and interpretation. The differences between investigators performing the US showed moderate to good correlation for PCISA and good to excellent correlation for IPD. Image interpretation had less consistency, with fair to moderate correlation for IPD and moderate to good correlation for PCISA.

Traditionally, scaphoid malposition assessment relies on CT scans or indirect measurements of the carpal malalignment. The radiolunate (RL) angle is commonly used for DISI deformity assessment often present in scaphoid nonunions [21], showing reliability and correlation with clinical outcomes [22–26] and the H/L ratio [12]. However, its accuracy depends on wrist position in lateral radiographs [27], although it remains cost-effective and widely available as it is based on conventional x-ray. The LISA, initially described using trispiral tomography [6]. and later adapted to CT scans, has shown poor intra- and inter-rater reliability [10,26].

The H/L ratio correlates with the RL angle [12], a higher degree of malunion [26] and in consequence with the clinical outcome. Its intra- and interrater reliabilities were found to be good-to-excellent [26].

The DCA measurement shows a wide reliability range, from poor [11] to good inter-rater and good-to-excellent intra-rater reliability [26].

Our sonographic measurements align with these established methods, making IPD and PCISA promising measurements for assessing fragment malposition in scaphoid fractures (Fig. 6). This technique offers advantages over CT scan-based measurement, including availability, lower costs, and no radiation exposure [13–15]. As ultrasound use increases among hand surgeons [14], it could also aid in intraoperative scaphoid reduction. Another benefit is the possible use of the healthy contralateral scaphoid as a template, given the usual symmetry between scaphoids [28]. Adding this comparison, could even increase the reliability of this measurement in the clinical application.

However, potential disadvantages include human-dependent variations in image acquisition and interpretation, potentially adding to more important differences in between different investigators. Our study, initially tested on a healthy population, provides a baseline for IPD and PCISA values. However, the clinical aim of this measurements is to assess the fragment displacement in scaphoid fractures, which wasn't yet directly addressed in this study. In our opinion, it was the most appropriated way to start with assessing a healthy population to achieve a first validity of the measurement.

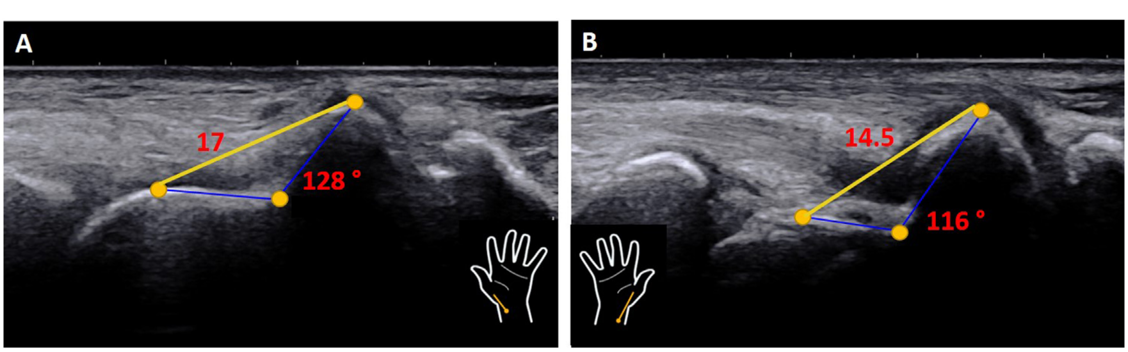

Fig. 6. Ultrasound image of a right scaphoid with a humpback deformity and comparison of the left wrist. The two measurements described (palmar cortical intra scaphoid angle [PCISA] and inter-pole distance [IPD]) are outlined, showing a clear difference in between both wrists.

In addition, we did not include a direct comparison to a gold standard due to ethical concerns about exposing volunteers to CT scan radiation.

5. Conclusion

This study introduces a cost-effective and accessible sonographic technique for measuring the intra-scaphoid angle. Further research is needed to evaluate its effectiveness in scaphoid fractures and compare it to CT-based measurements like the H/L ratio, LISA, and DCA.

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