Macroscopic and digital anthropometry of the human scaphoid: a comparative study

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SUMMARY

The purpose of this study was to establish an appropriate measurement system to accurately determine scaphoid anthropometry. It has been found that, following a scaphoid fracture, it is as important to achieve healing as it is to restore the bone's natural anatomy. To that end we performed an analysis comparing macroscopic caliper-based measurements with digital CT-based measurements of a 3D reconstructed scaphoid. A caliper was used to macroscopically measure twenty-six scaphoid specimens, evaluating length and thickness, both at the level of the waist and of the poles. Subsequently, a CT-scan was performed of all scaphoid specimens making the measurements once again with the same bone landmarks, but using the 3D CT reconstruction. Lastly, a comparative study was performed between the results of the two measuring systems employed.

A statistically significant mean difference was found ($p<0.05$) between the macroscopic and the digital measurements, both in terms of the length [0.51 mm (SD=0.79)] and the thickness of the waist [0.57 mm (SD= 0.76)]. This means that significant differences do exist between measuring the length and the thickness of the scaphoid waist digitally or with a caliper. Lastly, a comparison was made between the samples from the proximal pole with those from the distal pole. Although no significant differences were observed between one measuring system and the other with respect to the proximal pole, statistically significant differences were found regarding the distal pole measurements ($p=0.003$). Digital measurements were seen to be superior to macroscopic measurements, as they provided more reliable and accurate results. To minimize errors when making digital measurements it is essential to perform a CT-scan where slice interval is smaller than slice thickness. Moreover, female scaphoids have shown themselves to be morphometrically smaller than male scaphoids.

Keywords: Scaphoid bone – Anatomy – Fracture – Macroscopic measurement – Digital measurement

INTRODUCTION

Scaphoid fractures account for 11% of all hand fractures and 80% of carpal fractures (Arsalan-Werner et al., 2016). Depending on how stable the fracture may be, treatment may be conservative (in fractures with displacements <1 mm, a scapholunate angle <60º and a capito-lunate angle <15º); or surgical (rest of cases).

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The 70% of scaphoid fractures are stable fractures that affect the middle third where splinting treatment allows consolidation. However, it is subject to a long immobilization time and is not exempt from complications such as post-immobilization stiffness, consolidation in poor position with scaphoid flexion, which would lead to a SMAC wrist (Scaphoid Malunion Advanced Collapse), or nonunion. In the last 20 years, the advent of cannulated implants and the availability of more versatile instrumentation have turned percutaneous internal fixation into the primary treatment for acute scaphoid fractures, both in stable and unstable injuries, with healing rates of 95% (Letta et al., 2014).

The goal of surgical treatment is to achieve bone healing and restore scaphoid anatomy. To be successful, it is essential to have a good understanding of the bone's three-dimensional anatomy, its spatial orientation within the carpus, and its morphologic and morphometric variability. Several authors have examined the gender-related variations in scaphoid anthropometry or compared the variables associated to the macroscopic and digital measurements of the bone (Ceri et al., 2004; Crisco et al., 2005; Guo and Tian, 2011). Nevertheless, no studies have so far been performed comparing those two measurement systems and showing the superiority of one over the other. Within clinical practice, it is common to resort to macroscopic measurement of a piece intraoperatively to select implant sizing. However, correct preoperative planning is required, where 3-dimensional imaging tests provide complete information on the injury. In addition, in recent years much progress has been made in custom implants based on digital imaging tests.

The purpose of this study is to analyze how measurements may vary as a function of the measurement system employed. Our hypothesis is that no significant differences are obtained in scaphoid length and thickness when making the measurement macroscopically with a caliper on the anatomic specimen as compared to making it digitally from a computed tomography (CT) with 3D reconstruction. The study also included a gender-based comparison.

MATERIALS AND METHODS

The study was performed with 30 formaldehyde- and cryopreserved scaphoid specimens. In order to obtain the largest possible sample, different conservation methods have been used since they do not influence the morphometric and morphological study. The samples were in all cases extracted through a dorsal approach, sectioning the ligamentous attachments to the periscaphoid carpal bones, always sparing the cartilaginous cover of the joint surfaces.

Before starting the analysis, all the specimens were macroscopically examined. Four were excluded, because they presented with degenerative changes secondary to a previous condition, which could lead to a misleading result and distort our findings. Finally, the total number of scaphoid specimens included was 26 (15 females and 11 males), with a mean age of 70.3 years (range: 53-89 years). Of them, 14 were left (53.85%) and 12 were right (46.15%) scaphoids. Four of the anatomic specimens were obtained from independent cadavers, while the other 22 came from scaphoids on both sides of the same cadaver and between the two sides in the same individual.

Macroscopic measurement

The 26 scaphoid specimens selected were measured macroscopically with reference to different bone landmarks. The macroscopic measurement protocol required the use of a manual caliper graduated in 0.05 mm increments, and included an evaluation of both the longitudinal axis and the thickness of the transverse axis. For the measurement of length, one arm of the caliper was placed at the most prominent point of the proximal pole, and the other tangentially to the overhanging distal pole. In addition to the length measurement, using the above-mentioned line as a reference, the thickness of the scaphoid was measured in three areas: scaphoid waist, proximal pole, and distal pole. The waist thickness was measured at the narrowest part of the articulating surface with the capitate, perpendicularly to the longitudinal axis (Fig. 1). The thickness of both poles was also calculated perpendicularly to the longitudinal axis, but placing the caliper 2 mm from the apex of the proximal and distal joint surfaces, respectively (Heinzelmann et al., 2007).

Digital measurement

The 26 specimens were subjected to a second examination, but on this occasion using imaging techniques. A 64-detector row helical CT scanner (General Electric®, Milwaukee, WI, USA) was used to obtain continuous 0.625 mm-thick slices, ensuring that the slice interval was smaller than the slice thickness to reduce partial volume effects. Images were obtained at 120 kV and the beam pipe current was 335 mA. Results were transferred to a workstation (General Electric® Milwaukee, WI, USA) that was used as a basis to carry out the three-dimensional (3D) reconstruction from the different slices.

The length of the scaphoid was quantified using the 3D reconstructions of the bones with a measurement software that had a built-in micrometer. In all cases, length was determined by the same investigator, measuring the distance between the most prominent point of the proximal and the distal poles. Using this basic line and the sagittal aspect of the scaphoid as a reference, the central thickness of the scaphoid waist was calculated, at 2 mm from the proximal pole and 2 mm from the distal pole (Fig. 2).

Statistical analysis

The differences between both groups were statistically evaluated using the SPSS statistical package (SPSS for Windows 10.0, SPSS Inc, Chicago, IL.). The Kolmogorov- Smirnov test was used to evaluate the normality or goodness of fit of the sample; the mean and standard deviation (SD) of the data with normal distribution were calculated. Either student's T test or the Wilcoxon signed-rank test were applied to study the difference between the measurement systems, depending on the normality of the sample. Statistical significance was set at a p value <0.05.

RESULTS

The first analysis provided the mean values from the macroscopic measurements performed

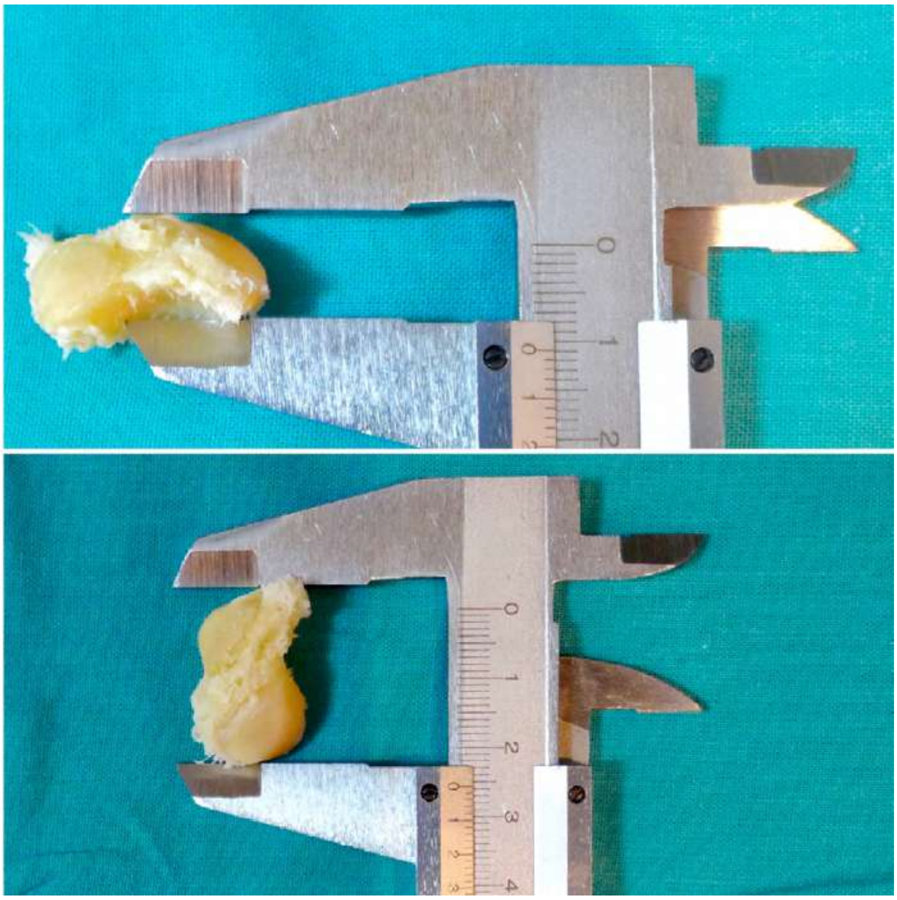

Fig. 1.- Macroscopic measurement with a manual caliper showing how thickness and scaphoid length are measured.

with the caliper. Measurements included the mean length of the scaphoid and mean scaphoid thickness at the level of the waist, the proximal pole, and the distal pole. Table 1 shows the overall mean values, as well as the mean values for males and females (columns 2 and 3). The mean values for the longitudinal axis and thickness across all magnitudes measured macroscopically were higher for males than for females.

This same table also shows the same length and thickness parameters but measured using the digital 3D CT-based technique using the General Electric® scanner, which incorporates a specific calculation software based on 3D CT reconstructions. Again, the values for the male specimens were higher than those for the female ones.

Once the macroscopic and digital measurements (all made by the same investigator) were completed, the results of both exercises were compared considering the sites described above. The purpose was to determine whether one measurement system was superior to the other, as this information would be extremely useful during preoperative planning to ensure a correct anatomic restoration. A student's test was carried out on paired simples following normality. Table 2 shows that a statistically significant mean difference was found between macroscopic and digital measurements both regarding length [0.51 mm (SD=0.79)] and thickness [0.57 mm (SD= 0.76)] of the scaphoid waist. Therefore, statistically significant differences do exist between measuring the length and thickness of the scaphoid wait macroscopically or digitally.

Lastly, a comparison was made between the proximal and the distal pole samples, using the Wilcoxon test. While no statistically significant differences were observed between the two measurement techniques at the proximal pole ($p=0.071$), such differences were found at the level of the distal pole ($p=0.003$).

There was no considerable difference between proximal pole, distal pole, waist or length measurement between the right and left sides in the same donor. Always finding minor differences with the macroscopic measurement.

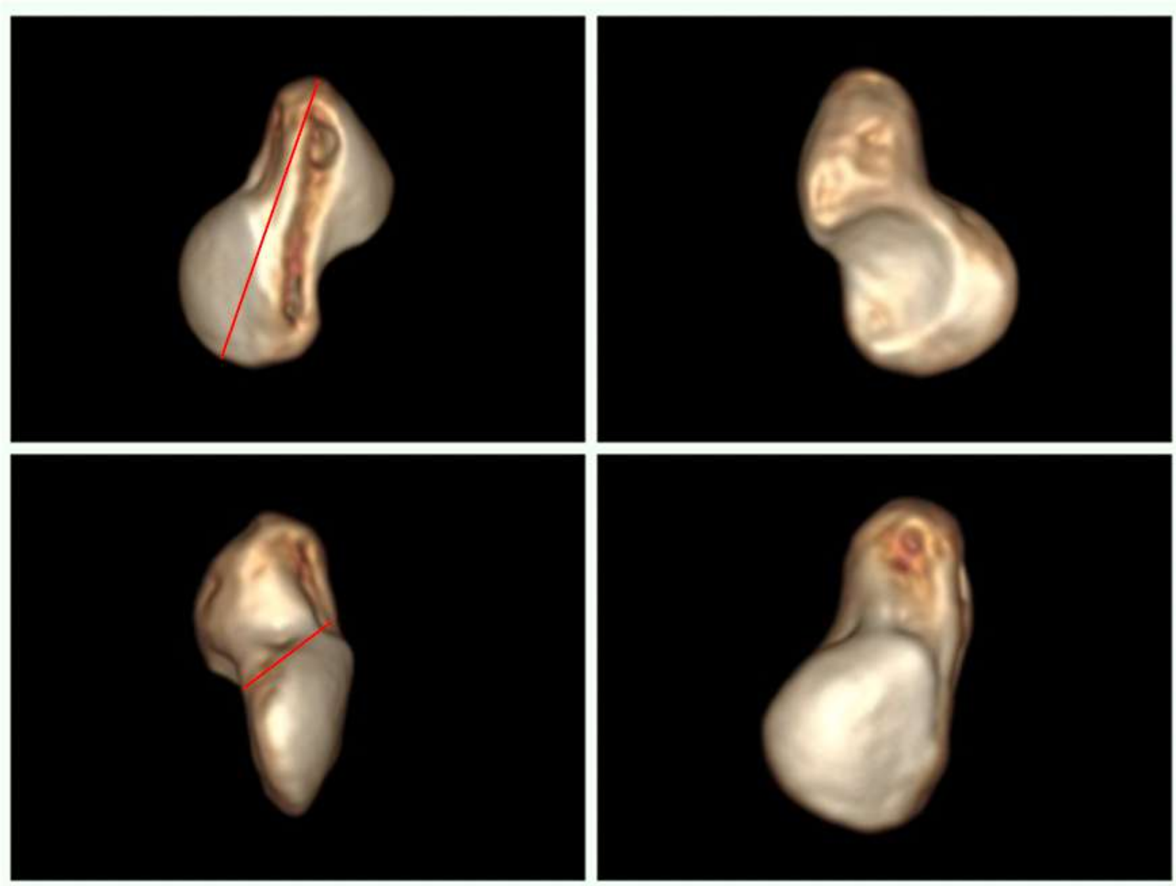

Fig. 2.- Three-dimensional CT reconstruction image for digital measurement.

DISCUSSION

Compson was one of the first authors to write on the importance of understanding the three-dimensional morphology of the scaphoid bone in clinical and surgical practice (Compson et al., 1994). Since then, different methods have been employed to make the relevant measurements, ranging from the use of calipers to the performance of bidimensional imaging tests or even magnetic resonance imaging (MRi) tests and 3D CT scans. Modern image processing techniques provide a better indication of the length, volume, and surface geometry of carpal bones as a whole, although few studies evaluate each of the bones individually (Fukuda et al., 2003).

The longitudinal axis, extending from the most prominent proximal and distal points of the scaphoid, represents the maximum length of the bone and is the reference for all other measurements used to calculate the bone´s thickness. In the first few studies published on the subject, this measurement was made macroscopically, but at present recourse is made to sophisticated imaging techniques such as CT or MRi, with or without 3D reconstruction, which provide more accurate findings and result in fewer errors (Compson et al., 1994; Ceri et al., 2004; Crisco et al., 2005; Guo and Tian, 2011; Heinzelmann et al., 2007).

Macroscopic measurement

The samples presented in this study had a mean length of 26.24 mm according to macroscopic caliper-based measurement (25.28 mm in females and 27.54 mm in males). A comparison with the results of other studies that use this measurement system shows that Heinzelmann, working on a sample of 30 pairs of cadaveric scaphoid specimens, obtained higher values than us, with a mean length of 27 mm in females and of 31 mm in males. Like us, he found that female

Table 1. Mean values obtained with the caliper-based measurement technique and with the digital 3D CT-based measurement technique.

	Macroscopic measurement with caliper			**Digital measurement by 3D CT**		
	Total Nr=26 Mean (range)	**Female Nr= 15 Mean (range)**	**Male Nr= 11 Mean (range)**	**Total Nr=26 Mean (range)**	**Female Nr= 15 Mean (range)**	**Male Nr= 11 Mean (range)**
Mean length (mm)	26.24 (23-31)	25.28 (23-28.5)	27.54 (23.5-31)	25.72 (22.7-29.5)	25.09 (22.7-28.5)	26.58 (24.1-29.5)
Mean waist thickness (mm)	9.66 (8-11.9)	9.40 (8.1-11.5)	10.01 (8-11.9)	9.08 (7.52-11)	8.78 (7.52-9.92)	9.49 (8-11)
Mean proximal pole thickness (mm)	5.14 (4-7)	5.06 (4-6)	5.42 (4.5-7)	4.96 (4.09-6.1)	4.79 (4.09-6.1)	5.19 (4.5-6)
Mean distal pole thickness (mm)	6.39 (5-9)	6.08 (5-7)	6.8 (5.5-9)	6.91 (5.7-8)	6.71 (5.77-7.7)	7.17 (5.7-8)

Table 2. Results of Student´s t test for paired samples.

	Paired differences					**Sig. (bilateral)**
				95% CI of the difference		
	Mean	**SD**	**Standard error of the mean**	**Inferior**	**Superior**	
Macrosc. length-CT Length (mm)	0.51	0.79	0.15	0.19	0.84	0.003
Macrosc. waist – CT Waist (mm)	0.57	0.76	0.15	0.26	0.88	0.001

scaphoids are always morphometrically smaller (Heinzelmann et al., 2007). One limitation of this study, however, is that it ignores the donors' racial background, which means that potential race-related size differences were not considered. Our sample is conversely solely made up of specimens from Mediterranean Caucasians. Another author using macroscopic measurements is Kong, who studied 84 scaphoids from a Chinese cohort where the mean length was much smaller than ours, ranging from 18 to 25 mm, indicating that scaphoid size in the Chinese population is smaller than among Caucasians (Kong et al., 2009). Ceri et al. (2004) also conducted a macroscopic evaluation of scaphoids and found a mean length of 25.8 mm, although, like Heinzelmann, he does not provide demographic or gender-related data on his sample.

With respect to the other morphometric parameters measured using a caliper, our study obtained a mean thickness of 9.66 mm at the level of the waist, which ranged between 10.01 mm (males) and 9.40 mm (females). Ceri reports values of 10.9 mm for the waist whereas Heinzelmann obtained 13.6 mm in males and 11.1 mm in females (Ceri et al., 2004; Heinzelmann et al., 2007). At the level of the distal tubercle, our mean thickness value was 6.39 mm, which is in line with the value obtained by Heinzelmann (7.2 mm), the only author who evaluated the thickness of the poles with the same method used in this study. At the proximal tubercle, Heinzelmann's values range between 3.7 and 4.5 mm depending on sex (Heinzelmann et al., 2007). In our study, the variation was between 5.06 mm in women and 5.42 mm in men.

Digital measurement

The same measurements were performed again on every specimen on the basis of a 3D CT reconstruction using a computer measurement software that allows ranges to be manually selected. This calculation system has been used by multiple authors like Fukuda et al. (2003), Ring et al. (2005), Letta et al. (2014), Crisco et al. (2005), Smith and Maj (1993) and Pichler et al. (2010). Table 3 shows the mean length results of our study, and is compared with the rest of the publications that use the same measurement system, although each one uses different samples that range from 26 to 100 scaphoids (Table 3). It should be noted that Guo, to avoid manual errors, used a software that avoids intra- and interobserver variability in the setting of boundary values (Guo and Tian, 2011).

As in other studies, scaphoid length in our study was shorter in females. To date, Crisco has been the only author to quantify this size difference in an attempt to determine the role played by gender. He found shorter lengths not only in the scaphoid (24.8 mm vs 29.3 mm for males) but also in the rest of female carpal bones (Crisco et al., 2005).

In short, the values obtained in our study are similar to those reported in the literature, with differences ranging between 1 and 1.5 mm. Only Smith obtained (considerably) lower values; other authors found anthropometrically higher values (Smith and Maj, 1993). As regards measurements

Table 3. Bibliographic results of mean scaphoid length after digital measurement.

	Sample (N)	Mean length Total (mm)	Mean length Male (mm)	Mean length Female (mm)
Gómez-Barbero	26	25.72	26.58	25.09
Smith	100	24.5	26	22
Fukuda	51	27.8	29.2	25.9
Patterson	35	27.35	29.2	25.5
Letta	52	26.8	28	25.1
Pichler	30	26	27.8	24.5
Guo	30	28	29	27
Crisco	28	27	29.3	24.8

other than those of scaphoid length, our literature search has not found any article that makes a digital evaluation scaphoid thickness at the level of the wait or the poles.

Comparison between macroscopic and digital measurements

The main goal of the present study was to compare the mean values obtained following a macroscopic caliper-based measurement with the values obtained from a digital measurement based on 3D CT reconstruction. Our analysis found statistically significant differences between the two measurement techniques in terms of mean length, waist thickness and proximal pole thickness. Such differences were not found at the level of the proximal pole. It does seem, therefore, that using one method rather than the other could yield different results.

Most articles in the literature mention the superiority of imaging techniques with 3D reconstruction when it comes to planning a surgical procedure, especially for reconstructing the hand following complex fractures (Letta et al., 2014). However, no study provides a comparison between the two measurement techniques.

It is a known fact that macroscopic caliper-based measurements are less precise because of errors typically inherent in manual calculations and due to the device's geometrical tolerance. Although a 3D CT system allows magnification of many details, this technique is not exempt from measurement errors, owing to the interval that exists between the CT slices (0.5 mm) and the accuracy of the CT scanner and of the image reconstruction and processing procedures. In our case, slice intervals were adjusted to be smaller than the thickness of the slices to reduce partial volume effects and allow a precise resection. Moreover, in cases where digital measurements are made, it is typically the investigators themselves that manually determine the measurement points (Fukuda et al., 2003). This limitation can be overcome by recourse to measurement systems such as the one proposed by Guo, which generates measurements on the basis of a computer software (Guo and Tian, 2011).

Our study is the first of its kind to compare the two most common measurement systems. All the measurements made using CT-scans met the normality criterion ($p > 0.05$), while the macroscopic measurements at the level of the poles showed more dissimilar values. For those reasons, we believe that digital measurements based on 3D reconstruction are more accurate and, therefore, more reliable and preferable for a proper anatomic study of the scaphoid, thus ruling out our null hypothesis. In addition, in clinical practice the use of digital measurement shows a double advantage, since it allows us to know the morphology of the lesion in the damaged scaphoid and to plan the definitive treatment; but also to study, from the healthy contralateral scaphoid that is symmetrical, its original anatomy and even manufacture an implant as it reconstructs the damaged bone part (Ten Berg et al., 2015).

Finally, we did not find differences between the left and right scaphoid measurements within the same individual, regardless of the measurement system used. As we have said before, the fact of not finding significant differences has a marked clinical relevance, since in the case of a fracture or pseudoarthrosis, the X-ray of the healthy hand can be taken as a template to plan the reconstruction. This idea has been estimated and proposed by other authors with Heinzelmann et al. (2007), Guo and Tian (2011), Fukuda et al., 2003) or Letta et al. (2014). Only Ceri observed a greater development of the scaphoids as a function of the patient's dominant hand based on Wolff's law (Ceri et al., 2004).

One of the strengths of this study is that it included a large enough sample to produce significant results on a series of scaphoid specimens with no previous history of degenerative changes. However, it must be considered that, as the specimens were obtained through donations, their bone age was usually rather advanced.

REFERENCES

ARSALAN-WERNER A, SAUERBIER M, MEHLING IM (2016) Current concepts for the treatment of acute scaphoid fractures. Eur J Trauma Emerg Surg, 42(1): 3-10.

CERI N, KORMAN E, GUNAL I, TETIK S (2004) The morphological and morphometric features of the scaphoid. J Hand Surg Br, 29(4): 393-398.

COMPSON JP, WATERMAN JK, HEATLEY FW (1994) The radiological anatomy of the scaphoid. Part 1: Osteology. J Hand Surg Br, 19(2): 183-187.

CRISCO JJ, COBURN JC, MOORE DC, UPAL MA (2005) Carpal bone size and scaling in men versus in women. J Hand Surg Am. 30(1): 35-42.

FUKUDA S, ISHIDA O, KIDO M, SUZUMURA F, IKUTA Y (2003) A morphological study of the scaphoid using a mathematical technique and comparative study of the three-dimensional measurements of the scaphoid. Hand Surg, 8(2): 157-161.

GUO Y, TIAN GL (2011) The length and position of the long axis of the scaphoid measured by analysis of three-dimensional reconstructions of computed tomography images. J Hand Surg Eur Vol, 36(2): 98-101.

HEINZELMANN AD, ARCHER G, BINDRA RR (2007) Anthropometry of the human scaphoid. J Hand Surg Am, 32(7): 1005-1008.

KONG W, XU Y, WANG Y, CHEN S, LIU Z, LI X (2009) Anatomic measurement of wrist scaphoid and its clinical significance. Chinese J Traumatol English Ed. 12(1): 41-44.

LETTA C, SCHWEIZER A, FÜRNSTAHL P (2014) Quantification of contralateral differences of the scaphoid: a comparison of bone geometry in three dimensions. Anat Res Int, 2014: 904275.

PICHLER W, WINDISCH G, SCHAFFLER G, HEIDARI N, DORR K, GRECHENIG W (2010) Computer-assisted 3-dimensional anthropometry of the scaphoid. Orthopedics, 33(2): 85-88.

RING D, PATTERSON JD, LEVITZ S, WANG C, JUPITER JB (2005) Both scanning plane and observer affect measurements of scaphoid deformity. 2005:696-701.

SMITH D, MAJ U (1993) Anatomic features of the carpal scaphoid: Validation of biometric measurements and symmetry with three-dimensional MR imaging. Radiology, 187: 187-191.

TEN BERG P, DOBBE JG, STRACKEE SD, STREEKSTRA GJ (2015) Three- dimensional assessment of bilateral symmetry of the scaphoid: An anatomic study. Biomed Res Int, 2015: 547250.