Abstract

Scaphoid fracture fixation using a cannulated headless compression screw and the Matti-Russe procedure for the treatment of scaphoid nonunions are performed routinely. Surgeons performing these procedures need to be familiar with the anatomy of the scaphoid. A literature review reveals relatively few articles on this subject. The goal of this anatomical study was to measure the scaphoid using current technology and to discuss the findings with respect to the current, relevant literature.

Computed tomography scans of 30 wrists were performed using a 64-slice SOMATOM Sensation CT system (resolution 0.6 mm) (Siemens Medical Solutions Inc, Malvern, Pennsylvania). Three-dimensional reconstructions from the raw data were generated by MIMICS software (Materialise, Leuven, Belgium). The scaphoid had a mean length of 26.0 mm (range, 22.3-30.7 mm), and men had a significantly longer ($P<.001$) scaphoid than women (27.86±1.6 mm vs 24.56±1.6 mm, respectively). The width and height were measured at 3 different levels for volume calculations, resulting in a mean volume of 3389.5 mm$^3$. Men had a significantly larger ($P<.001$) scaphoid volume than women (4057.8±740.7 mm$^3$ vs 2846.5±617.5 mm$^3$, respectively).

We found considerable variation in the length and volume of the scaphoid in our cohort. We also demonstrated a clear correlation between scaphoid size and sex. Surgeons performing operative fixation of scaphoid fractures and corticocancellous bone grafting for nonunions need to be familiar with these anatomical variations.

Fixation of scaphoid fractures with a cannulated headless compression screw has become a standard technique in recent years.\(^1\)\(^-\)\(^3\) The technique as well as the implants used in scaphoid fixation have undergone change over the past century.\(^4\)\(^-\)\(^6\) The Matti-Russe procedure for scaphoid nonunions, originally described by Matti\(^7\) and subsequently modified by Russe\(^8\)\(^,\)\(^9\) has become a benchmark technique.\(^10\)

We hypothesized that knowledge of the volume and length of the scaphoid would be helpful in the selection of an appropriately sized screw and resection of the correct volume of bone graft. A review of the literature revealed a paucity of published articles about the morphological variations in size and volume of this bone.\(^11\)\(^-\)\(^14\) The goals of this study were to measure the length and calculate the volume of the scaphoid using current technology and to determine if any correlations exist between scaphoid size (volume and length) and sex or side.

Materials and Methods
Thirty cadaveric wrists, preserved according to Thiel's method, were examined. This special embalming technique has been developed over a 30-year period in our institution. Extremities with arthrosis, evidence of trauma, or other pathological changes were excluded from this study. Thirty distal forearm and hands—15 left and 15 right specimens from 30 different cadavers—were chosen. The sample, therefore, represented 30 different individuals, to minimize the influence of symmetry. Mean age of the cadavers was 72.5 years (range, 59-98 years). Fourteen were men and 16 were women.

Computed tomography (CT) scans of the 30 wrists were performed using a 64-slice SOMATOM Sensation CT system (Siemens Medical Solutions Inc, Malvern, Pennsylvania). The wrists were scanned in a supine position, with 0.6 mm contiguous axial slices. DICOM raw data sets were reconstructed using MIMICS 3-D software (Materialise, Leuven, Belgium) (Figure 1). All measurements were taken with this software.

Figure 1: Each point was verified in 3 different 2-D planes (axial, coronal, and sagittal) and in the reconstructed 3-D model simultaneously. Figure 2: Coronal view demonstrates levels of width measurement (1: 3 mm distal to the proximal pole; 2: waist; 3: 3 mm proximal to the distal pole).

Following 3-D reconstruction, the first reference point for measurements was set at the tip of the proximal pole, which was determined simultaneously in 3 different 2-D planes (axial, coronal, and sagittal) and in the reconstructed 3-D view (Figure 2). The second point was set at the tip of the distal articular surface, which was also determined by applying the same 4 criteria. The midpoint between the proximal and distal poles was assigned as the center of the scaphoid. The width and the height were measured at 3 different levels perpendicular to the long axis of the scaphoid. The curved taper of the proximal and distal articulating surfaces accounts for 3 mm at either end of the scaphoid. Hence the measurements were taken 3 mm distal to the proximal pole and 3 mm proximal to the distal articular surface as well as at the center point representing the waist (Figure 3). The volume of the scaphoid was calculated from 16 different points: the tip of the proximal pole, tip of the distal articular surface, width and height measurement points at the 3 different levels already described, and anterior and posterior margins of the tubercle.
Figure 3: Three dimensional view of the volume measuring model; the volume of the scaphoid was calculated using 16 different nodes on the bone surface.

All measurements were performed independently by 2 observers well versed with this software. To check the reproducibility and accuracy of our measurement protocol, each observer performed 5 sets of measurements on 1 specimen. The variation was ±0.5 mm for all the measured dimensions. We felt this to be adequate for the purposes of this study. After establishing the measurement routine, further calculations were automatically performed by the MIMICS software. All statistical calculations were performed using Microsoft Excel 2003 (Microsoft, Redmond, Washington). Student t test was used for statistical analysis, and a P value ≤.05 was considered statistically significant.

Results

The mean distance between the proximal and the distal poles of the scaphoid was 26.0 mm (range, 22.3-30.7 mm; standard deviation [SD] ±2.3 mm). Men had a longer scaphoid than women (27.8±1.6 mm vs 24.5±1.6 mm, respectively). Correlation between sex and length was statistically significant (P<.001). The mean proximal width was 7.1 mm (range, 5.2-10.1 mm; SD ±1.2 mm). The mean proximal height was 12.5 mm (range, 9.2-16.7 mm; SD±1.7 mm). At this level, men had a wider and higher scaphoid compared to women (width: 7.8±1.3 mm vs 6.5 ±0.8 mm, respectively; height: 12.8±1.7 mm vs 12.2±1.6 mm, respectively); however, a statistically significant correlation was only found between gender and width (P=.005).

The mean width at the waist was 8.6 mm (range, 7.2-10.8 mm; SD ±1.1) and the mean height was 14.9 mm (range, 11.1-18.6 mm; SD ±1.8). At this level, men had a wider and higher scaphoid compared to women (width: 9.4±1.1 mm vs 7.9±0.6 mm, respectively; height: 15.5±1.5 mm vs 14.5±1.9 mm, respectively). A statistically significant correlation was only found between sex and width (P<.001).

The mean distal width was 9.2 mm (range, 6.5-12.6 mm; SD ±1.7), and the mean distal height was 11.9 mm (range, 8.3-15.6 mm; SD ±2.0). At this level, men had a wider and higher scaphoid compared to women (width: 10.1±1.7 mm vs 8.5±1.5 mm, respectively; height: 12.6±2.3 mm vs 11.4±1.6 mm, respectively), and the statistically significant correlation was between sex and width (P=.01).

The mean volume was 3389.5 mm$^3$ (range, 1949.5-5472.1 mm$^3$; SD: 902.9). Men had a significantly larger scaphoid volume than women (4057.8±740.7 mm$^3$ vs 2846.5±617.5 mm$^3$, respectively; P<.001). No statistically significant correlations between side, age, and this measurement were found (P>.05).

Discussion

The scaphoid is the most commonly injured bone of the carpus. Intramedullary fixation of the scaphoid with a single screw was described as early as 1954 by McLaughlin and with the use of a cannulated screw from 1970. Herbert and Fisher designed the headless differential pitch compression screw in 1977.
and reported excellent results with this implant. This modification of the screw design popularized the internal fixation for the treatment of scaphoid fractures.\textsuperscript{1-3}

Despite the increasing popularity of scaphoid fixation, there is a paucity of articles on its morphology and size. Our review of the current literature identified only 1 paper on the subject. Heinzelmann et al\textsuperscript{13} measured the length and width of the scaphoid in 30 paired cadaveric specimens with a sliding caliper. The first objective of our study was to accurately measure length, width, and height of the scaphoid using current technology.

Our results differ from Heinzelmann et al's\textsuperscript{13}: The measured length (men, 27.8±1.6 mm; women, 24.5±1.6 mm) is significantly shorter than the length measured by Heinzelmann et al\textsuperscript{13} (men, 31.3±2.1 mm; women, 27.3±1.7 mm). The mean scaphoid width measured in our study (men, 9.4±1.1 mm; women, 7.9±0.6 mm) also differs from that measured by Heinzelmann et al\textsuperscript{13} (men, 13.6±2.6 mm; women, 11.1±1.1 mm). The comparison of the dimensions of the proximal and distal poles, however, were made from different anatomical locations and are not comparable. Reasons for this discrepancy may be due to the techniques used (sliding caliper vs computer-aided CT analysis) and the different populations studied.

The computerized analysis may result in a significant reduction of measurement errors. The measurement markers are accurately set within the cortex using 4 different views simultaneously (axial, coronal, sagittal 2-D, and 3-D). Thus, errors caused by adherent soft tissues are eliminated. Using a sliding caliper makes it impossible to only measure the bony dimensions, as the surrounding cartilage is also measured.

Morphometrical data from the scaphoid of non-white races have also been reported. Kong et al\textsuperscript{14} measured 47 wet and 36 dry scaphoids in Chinese patients and reported results similar to ours (length: men, 27.9±2.46 mm; women, 26.5±0.6 mm; width: men, 10.7±1.2 mm; women, 10.4±0.9 mm).

Screw sizes available for scaphoid fixation are between 10 and 30 mm. Current literature suggests using a screw 4 mm shorter than the measured length of the scaphoid.\textsuperscript{13} This 4-mm deduction from the mean scaphoid length in our study results in an average screw size of 24 mm for men and 21 mm for women.

Scaphoid nonunions remain a challenging and controversial problem. The technique of inserting a corticocancellous graft across the nonunion defect and packing of the surrounding area with cancellous bone through a volar approach is referred to as the Matti-Russe procedure. In 1936, Matti\textsuperscript{7} described excavating the avascular bone and detritus at the nonunion site through a dorsal approach and filling of the defect with nonvascularized cancellous bone. In 1960, Russe\textsuperscript{9} modified this technique to its currently described form.

The second objective of our study was to measure the width and height of the scaphoid and to calculate volume of the bone. Knowledge of the average size and volume of the scaphoid may be helpful in resecting an appropriately sized bone graft from the iliac crest or the distal radius for the Matti-Russe procedure. Murase et al\textsuperscript{19} examined the effectiveness of preoperative 3-dimensional computer simulations in scaphoid nonunion surgery. The estimated bone defect and the appropriate site and direction of the screw insertion were simulated. The authors concluded that preoperative 3-dimensional computer simulations are useful for accurate correction of scaphoid nonunions.\textsuperscript{19}

We measured the width and the height of the scaphoid at 3 different levels and calculated the volume of the whole bone. Men have an average scaphoid volume of 4057.8 mm\textsuperscript{3} and women of 2846.5 mm\textsuperscript{3}. Russe\textsuperscript{9} recommends taking an oblong piece of cancellous bone from the patient’s opposite iliac crest, approximately 20×10×10 mm, and forming a peg ranging from 12×4×4 mm to 15×6×5 mm amid small chips.

Prediction of the possible size of the bone defect is dependent on a multitude of parameters (eg, bone size, lysis, bone vitality). We assumed a standard defect to leave the scaphoid as a 3-mm-thick cortical shell. The mean size of this hypothetical bone defect is 18.5±5.10.7 mm (men, 20.5±6.5±11.6 mm; women, 17×4.7±10 mm). According to our hypothetical bone defect, the size of the bone graft Russe\textsuperscript{9} recommended should be appropriate in all cases. The knowledge of the possible size of the defect is important for the planning and fashioning of the ideal graft for scaphoid nonunion surgery. Recent advances have extended the indications for the use of artificial bone grafts. With the knowledge of the variations in the volume and dimensions of the scaphoid, it may be possible to manufacture bespoke structural grafts for
the treatment of scaphoid nonunions. These grafts will require osteoinductive as well as osteoconductive properties.

**Conclusion**

Considerable variation was found in the length and volume of the scaphoid in our cohort. We also demonstrated a clear correlation between scaphoid size and sex. Our data are restricted to a European white population. Surgeons performing operative fixation of scaphoid fractures and corticocancellous bone grafting for nonunions need to be familiar with these anatomical variations.

**References**


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Drs Pichler, Windisch, Schaffler, Dorr, and Grechenig and Ms Heidari have no relevant financial relationships to disclose.

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