1-1-2019

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Citation of this paper:

Wu, Kitty; Padmore, Clare; Lalone, Emily; and Suh, Nina, "An Anthropometric Assessment of the Proximal Hamate Autograft for Scaphoid Proximal Pole Reconstruction" (2019). *Bone and Joint Institute*. 746.
<https://ir.lib.uwo.ca/boneandjointpub/746>

An Anthropometric Assessment of the Proximal Hamate Autograft for Scaphoid Proximal Pole Reconstruction

Kitty Wu, MD,* Clare Padmore, MEng,† Emily Lalone, PhD,‡ Nina Suh, MD‡

Purpose Fragmentation of the scaphoid proximal pole secondary to avascular necrosis presents a difficult reconstructive problem. This anthropometric study assesses the utility of the ipsilateral proximal hamate for complete osteochondral scaphoid proximal pole reconstruction.

Methods Twenty-nine cadaveric specimens underwent computed tomography scanning and 3-dimensional reconstruction of the carpus and distal radius. Scaphoid height was measured and a third of its height was used to simulate resection of the proximal scaphoid pole and extent of hamate autograft required. The proximal scaphoid and hamate were divided into 6 sections, and compared using an iterative point-to-point distance algorithm. Average distance between the scaphoid and the hamate surfaces was determined. An interbone algorithm was used to assess radioscaphoid joint congruency and articular contact surface of the native scaphoid compared with the scaphoid reconstructed with hamate autograft.

Results The mean height of scaphoid proximal pole excision and proximal hamate autograft height was 9.3 mm. Comparing the morphology of the native scaphoid and hamate autografts, the absolute distances were the largest in the volar radioscaphoid, dorsal radioscaphoid, and dorsal scaphocapitate segments. Without osteotomy, the hamate autograft may cause impaction in the dorsal-radial aspect of the distal radius. The hamate autograft also shifted the articular contact point of the radioscaphoid joint toward the dorsal-radial position. Nine hamate autografts were classified as poor-fitting. Poor-fitting specimens had a greater radial styloid to distal radioulnar joint distance. These specimens also had wider hamates and scaphoids in the radial-ulnar dimension and wider scaphoids in the volar-dorsal dimension. Lunate type did not correspond to anthropometric fit.

Conclusions The proximal hamate osteochondral graft was poor fitting in 31% of cases (9 of 29 specimens). Wrists with radial-ulnar hamate width less than 10 mm, radial-ulnar scaphoid width less than 10 mm, and volar-dorsal scaphoid width less than 16 mm demonstrate better anthropometric fit.

Clinical relevance This study provides an anthropometric assessment of the recently described proximal hamate autograft, a new bone graft option for proximal scaphoid pole reconstruction. (*J Hand Surg Am.* 2019;44(1):60.e1-e8. Copyright © 2019 by the American Society for Surgery of the Hand. All rights reserved.)

Key words Autologous bone grafts, avascular necrosis, proximal pole scaphoid fracture, scaphoid nonunion.

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Received for publication September 25, 2017; accepted in revised form April 18, 2018.

No benefits in any form have been received or will be received related directly or indirectly to the subject of this article.

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0363-5023/19/4401-0011\$36.00/0
<https://doi.org/10.1016/j.jhssa.2018.04.021>

FRACTURES OF THE PROXIMAL POLE of the scaphoid are challenging to manage owing to the small proximal fragment size and tenuous blood supply. Compared with other fracture patterns, proximal pole fractures have a higher rate of nonunion, ranging from 5% to 50%.^{1–5} The proximal pole is especially susceptible to vascular injury^{5,6} and avascular necrosis is a serious late complication that occurs in 13% to 47% of proximal pole fractures.^{3,7,8} This can further lead to secondary fragmentation of the proximal pole and sclerosis of the fracture fragment.⁴

Proximal pole scaphoid nonunions may be managed using nonvascularized bone grafts from the distal radius or iliac crest⁹ or vascularized bone grafts from the distal radius or medial femoral condyle.^{6,9,10} If the proximal pole becomes fragmented in the setting of avascular necrosis, it becomes exceedingly difficult to reconstruct and surgical options become limited. In such scenarios, if the scapholunate ligament is intact, small fragments can be excised and the scapholunate ligament can be advanced.¹¹ Rib autografts and free vascularized osteochondral flaps from the medial femoral trochlea have been proposed for proximal scaphoid arthroplasty with varying success rates and concerns of donor site morbidity.^{12–14} Harvest of the rib autograft carries the risk of pleural tears and pneumothorax and free vascularized osteochondral flaps require microsurgical expertise.

The ipsilateral proximal hamate autograft was recently described for scaphoid nonunion with an unsalvageable proximal pole.¹⁵ The proximal hamate autograft is turned 180° so that the capitohamate articular surface becomes the reconstructed scapho-capitate articular surface and is then transfixed using a compression screw. The results were encouraging in 1 patient who remained asymptomatic at 3.5-year follow-up.¹⁵ The proximal hamate autograft is harvested within the carpus, avoiding the additional surgical site required in rib, iliac crest, and medial femoral condyle grafts, and has the advantage of bringing in a graft fully covered by healthy articular cartilage.

The objective of this study was to perform an anthropometric analysis of the proximal hamate autograft to investigate its suitability for proximal scaphoid pole reconstruction. Furthermore, we aimed to determine the impact of the proximal hamate autograft on the radioscapoid joint and to define imaging criteria that corresponded to better anthropometric fit. We hypothesized that the proximal hamate would be suitable for proximal scaphoid pole reconstruction in carefully selected patients and that

patients with type 2 lunates would demonstrate poorer morphological fit.

MATERIALS AND METHODS

Thirty intact frozen upper-limb cadaveric specimens, without prior history of upper limb or carpal pathology (mean age, 70 ± 11.28 years; 15 males, 15 females), underwent computed tomography (CT) using a GE Discovery CT750 HD (GE, Waukesha, WI) to identify the carpal bones, radius, and ulna of the right upper extremity. Given the limited experience and single case report on this procedure, this study was designed as an exploratory pilot study. Thirty specimens were selected based on institutional availability of cadaver specimens for a sample of convenience with 15 male and 15 female specimens. The position of 1 male specimen precluded adequate CT scanning and was thus excluded. A senior hand surgeon (N.S.) classified each wrist as having a type 1 or type 2 lunate. Then CT visualization software (Mimics Research 17.0, Materialise, Ann Arbor, MI) was used to execute a threshold-based semi-automated segmentation of the scaphoid, hamate, and radius. Subsequently, 3-dimensional reconstruction models of the bones of interest were created (Fig. 1A), exported as stereolithography files, and remeshed to create an optimized uniform triangulated surface mesh.

The hamate was then translated, aligning the proximal and distal poles with those of the scaphoid along a horizontal plane. Using the 3-dimensional reconstructed volumes, the intact hamate was then rotated 180° horizontally so that the capitohamate articular surface of the hamate becomes the scapho-capitate surface of the reconstructed scaphoid (Fig. 1B). The length of the scaphoid was measured from proximal pole to distal pole, and a third of the measured length was used to delineate the most distal extent of the proximal scaphoid (Fig. 1B).¹⁶ Simulated osteotomies were performed using the same angle of cut for both the scaphoid and the hamate to create a scaphoid proximal pole fracture fragment and corresponding hamate fragment. At the cut surface, the widest radial-ulnar and volar-dorsal dimensions for the scaphoid and hamate proximal poles were recorded. A coarse alignment of the hamate autograft and proximal scaphoid fragment was performed using a paired point registration algorithm, based on 3 sets of manually selected points (Fig. 1C–F). The alignment of the hamate fragment was then further refined using a least-square Iterative Closest Point algorithm (Visualization Toolkit; Kitware, Clifton Park, NY) to determine the best geometric position and orientation

FIGURE 1: Three-dimensional reconstructions and simulation of proximal scaphoid arthroplasty with proximal hamate autograft. Specimens underwent computed tomography scanning and reconstruction using threshold-based semiautomated segmentation. **A** Three-dimensional reconstructed volumes of the scaphoid and hamate. **B** The hamate is aligned with the scaphoid and rotated 180° so that the capitolunate articular surface becomes the reconstructed scaphocapitate articular surface. The dark bolded line indicates the level of intended osteotomy to form the proximal pole scaphoid fragment and hamate autograft. Level osteotomy chosen at one-third of the height of scaphoid from proximal to distal pole. Representations of a reconstructed scaphoid with opposed hamate autograft viewed from the **C** scaphocapitate, **D** volar, **E** radioscapoid, and **F** dorsal surfaces.

by minimizing the distance between the surfaces of the hamate fragment and the scaphoid.

The overlaid proximal scaphoid fragment and proximal hamate fragment were then divided into 6 equivalent sections for closer comparison: dorsal scaphocapitate, middle scaphocapitate, volar scaphocapitate, dorsal radioscapoid, middle radioscapoid, and volar radioscapoid (Fig. 2). A previously described point-to-point distance algorithm¹⁷ was employed to measure the mean absolute distance between the surfaces of each of the 6 sections of the proximal hamate fragment and proximal scaphoid to examine the goodness of fit for the hamate fragment. An absolute distance greater than 1 mm between the native proximal scaphoid and the hamate fragment in any of the 6 segments was considered poor-fitting.

The native proximal scaphoid fragment was then replaced by the proximal hamate fragment while maintaining its alignment. The joint congruency of the intact radioscapoid joint and the newly reconstructed radioscapoid articulation was calculated using a previously validated, custom, interbone distance algorithm.^{18,19} This produced proximity color maps corresponding to the measured distance between the 2 surfaces. To visualize the impact of the hamate fragment on distal radius articular contact location, the centroid of articular contact area patch

was calculated for each intact scaphoid and compared with the reconstructed scaphoid. A local coordinate system was generated for each specimen to normalize the centroid values between specimens and to account for size discrepancies. The origin of the coordinate system was located at the intersection between the midpoint of the volar midridge and the dorsal midridge and the midpoint of the radial styloid and the distal radioulnar joint.

Data analysis

The data collected were analyzed using descriptive statistics. Two-tailed Student *t* tests were used to compare scaphoid lengths between males and females, to compare dimensions of the proximal scaphoid and proximal hamate fragment with good and poor anthropometric fit, and to compare the displacement of the articular centroid between native and reconstructed radioscapoid joint. The proportion of type 1 and type 2 lunates in specimens with good and poor fit was assessed using Fischer exact test.

RESULTS

The mean scaphoid height measured from proximal to distal scaphoid poles was 27.9 ± 3.0 mm. The mean height of scaphoid proximal pole excision and mean proximal hamate fragment height was 9.3 ± 1.0 mm. In all specimens, the hook of the

FIGURE 2: Comparison of distances between aligned scaphoid fragment and hamate autograft surfaces. The proximal scaphoid fragment (blue) and proximal hamate autograft (red) viewed from the **A** superior and **B** volar aspects were aligned using the least-square Iterative Closest Point algorithm (Visualization Toolkit, Clifton Park, NY). Both were divided in 6 segments for comparison: dorsal radioscaphoid (I), middle radioscaphoid (II), volar radioscaphoid (III), dorsal scaphocapitate (IV), middle scaphocapitate (V), and volar scaphocapitate (VI). A point-to-point distance algorithm was then used to measure the average absolute distance in each of the 6 segments between the proximal scaphoid and the hamate autograft surfaces.

hamate was more distal to the level of osteotomy required and the mean hamate height proximal the hamate hook was 11.2 ± 1.5 mm (Table 1).

Comparing the dimensions of the scaphoid and hamate at the level of osteotomy, the scaphoid was wider than the hamate in the volar-dorsal dimension in 24 of 29 specimens (mean hamate width, 13.9 ± 2.4 mm; mean scaphoid width, 16.8 ± 2.0 mm), leaving the hamate fragment slightly deficient in volar-dorsal width at the dorsal most region (Table 1). In the radial-ulnar dimension, the hamate was wider in 28 of 29 specimens. After alignment, this excess radial-ulnar width was seen predominantly in the volar and dorsal radioscaphoid region as the hamate contour begins to flare and widen into the 2 articular surfaces for the fourth and fifth metacarpals. Corresponding to this, the mean absolute distances between the surfaces of the proximal hamate fragment and the aligned proximal scaphoid was greatest in the volar radioscaphoid (mean distance, 0.736 ± 0.290 mm) and dorsal radioscaphoid (mean distance, 0.751 ± 0.316 mm) segments. The hamate tended to be undersized in the volar scaphocapitate (83% specimens) and dorsal scaphocapitate segments (55% specimens) and oversized in the middle scaphocapitate (55% specimens) and dorsal radioscaphoid segments (52% specimens) (Fig. 3).

Proximity color maps of the radioscaphoid joint calculated from the interbone algorithm show impaction on the dorsal radial aspect of the distal

TABLE 1. Scaphoid and Hamate Measurements for All Specimens

Measurement	Mean, mm ($\pm$ SD)	Range (mm)
Height of scaphoid	27.9 ± 3.0	23.3–27.8
Height of proximal scaphoid fragment	9.3 ± 1.0	7.8–9.2
Height of hamate autograft	9.3 ± 1.0	7.8–9.2
Height of hamate hook	11.2 ± 1.5	8.6–14.2
Scaphoid V-D width	16.8 ± 2.0	12.8–14.2
Scaphoid R-U width	10.1 ± 1.2	7.1–12.3
Hamate V-D width	13.9 ± 2.4	10.0–20.1
Hamate R-U width	11.9 ± 2.2	8.2–15.6

R-U, radial-ulnar width; V-D, volar-dorsal width.

radius with the hamate fragment compared with the native scaphoid in 6 of the 9 poor-fit specimens (Fig. 4). Visualization of the articular contact location of the hamate fragment compared with the native scaphoid indicates a statistically significant shift of the centroid 1.99 mm toward the dorsal-radial aspect ($P < .05$) (Fig. 5). As a result, the dorsal radial aspect of the hamate fragment would require a substantial osteotomy to achieve adequate fit.

Of the 29 hamate fragments, 9 were classified as poor-fitting, defined as having a mean absolute distance greater than 1 mm in any of the six sections.

FIGURE 3: Anthropometric fit of proximal scaphoid fragment and hamate autograft. Native scaphoid (shaded gray) seen from the scaphocapitate and radioscaphoid views with superimposed hamate autograft of a representative specimen. Point-to-point distance algorithms demonstrate their anthropometric fit through color maps. Negative values (red) indicate regions in which the hamate autograft is larger than the scaphoid. Green indicates regions in which the distance between hamate and scaphoid surfaces are zero. Mean distances of all specimens are presented in the table at the bottom of the figure.

Out of these segments, the segment of worst fit was in the dorsal radioscaphoid region (5 of 9 specimens) or the volar radioscaphoid segment (4 of 9 specimens). Poor-fitting specimens had a greater radial styloid to distal radioulnar joint distance (mean, 32.3 ± 2.1 mm; $P < .05$) (Table 2). These poor-fit hamate fragments also had wider hamates (mean, 12.6 ± 2.4 mm; $P < .05$) and scaphoids in the radial-ulnar dimension (mean, 10.9 ± 1.0 , mm; $P < .05$) and wider scaphoids in the volar-dorsal dimension (mean, 18.6 ± 1.8 mm; $P < .05$). Of the 29 specimens, 18 had a type 1 lunate and 11 had a type 2 lunate. The proportion of specimens with good and poor anthropometric fit was similar between specimens with type 1 and type 2 lunates (Table 2).

DISCUSSION

This anthropometric study assessed the suitability of the ipsilateral proximal hamate for complete osteochondral reconstruction of the scaphoid proximal pole. Sixty-nine percent of the specimens demonstrated good anthropometric fit and 31% of specimens were poor fitting with the largest incongruities in the volar and dorsal radioscaphoid region. Specimens with poor fit had incongruity primarily in the dorsal and volar radioscaphoid

surfaces, corresponding to dorsal radial impaction on the distal radius and a shift of the articular contact point toward the dorsal radial aspect. Further intra-operative osteotomies may improve this; however, extensive contouring of the hamate in the region of the new radioscaphoid surface will remove the articular cartilage and may predispose to the development of radiocarpal arthritis. Given the high percentage of hamates that demonstrated poor fit, preoperative CT would be important for assessment of the morphology of the carpal bones for operative planning. Arthroplasty of the entire proximal pole was simulated in this study to provide the most conservative measurement of anthropometric fit. This study demonstrated that better-fitting specimens had smaller volar-dorsal and radial-ulnar measurements and, similarly, replacement of a smaller proportion of the proximal pole would likely yield better anthropometric fit.

The hamate osteochondral graft was recently described for reconstruction of unsalvageable proximal scaphoid poles with the possibility of scapholunate ligament reconstruction using the volar capitohamate ligament.¹⁵ Radial-ulnar hamate width less than 10 mm, radial-ulnar scaphoid width less than 10 mm, and volar-dorsal scaphoid width

FIGURE 4: Effect of hamate autograft on radioscapoid joint congruency. An example of the articular surface of the distal radius of 1 specimen. The interbone distance algorithm generated color maps demonstrating distance of either native scaphoid (left) or hamate autograft (right) on the distal radius. Regions in yellow and red indicate negative distances. Without osteotomy, the hamate autograft in 6 of 9 poor-fit specimens caused impaction on the dorsal-radial aspect of the radioscapoid articular surface.

FIGURE 5: Effect of hamate autograft on distal radius articular contact location. Articular surface of distal radius is illustrated with the origin of the coordinate system located at the intersection between the midpoint of the volar midridge and the dorsal midridge and the midpoint of the radial styloid and distal radial-ulnar joint. The centroid of articular contact is shown for the native scaphoid (white) and hamate autograft (black) ($n = 29$). There is a statistically significant shift of the centroid 1.99 mm toward the dorsal-radial direction with the hamate autograft.

less than 16 mm indicate more favorable morphology and are more likely to have a better anthropometric fit.

In this study, the proportion of hamate fragments with good and poor anthropometric fit was similar based on lunate type. Hamates in wrists with type 2 lunates were hypothesized to be wider owing to the extra-articular facet and thus have poorer fit. The incidence of type 2 lunates varies between 57.5% and 73% of the population.^{20–22} In our study, only 38% of specimens had a type 2 lunate, and thus, the sample was inadequately powered to detect a difference in anthropometric fit based on lunate type ($\beta = 0.52$). In a study of 393 cadaveric wrists, Viegas et al²¹ found that 38% of type 2 lunates had evidence

of arthrosis of the proximal pole of the hamate compared with only 2% of type 1 lunates. Type 1 lunates never contact the hamate; however, type 2 lunates make articular contact with the hamate when the wrist is ulnarly deviated.²³ In Viegas et al's study,²⁰ the mean age of wrists with evidence of arthrosis was 67 years compared with 54 years in wrists without. The presence of proximal hamate arthrosis would preclude the use of the proximal hamate as an autograft. Because radiographic imaging is often negative, additional preoperative magnetic resonance imaging studies should be considered for patients over the age of 55 years with identified type 2 lunates in whom this procedure is being considered.

TABLE 2. Comparison of Hamate Autografts With Good Fit and Poor Fit*

Measurement	Anthropometric Fit		P Value
	Good	Poor	
Number of specimens	20	9	
Radial-styloid – DRUJ (mm)	28.7 ± 3.4	32.3 ± 2.1	< .05
Hamate R-U width (mm)	10.3 ± 1.6	12.6 ± 2.4	< .05
Scaphoid R-U width (mm)	9.6 ± 1.1	10.9 ± 1.0	< .05
Hamate V-D width (mm)	13.4 ± 2.4	14.9 ± 1.5	.09
Scaphoid V-D width (mm)	16 ± 1.5	18.6 ± 1.8	< .05

DRUJ, distal radioulnar joint; R-U, radial-ulnar width; V-D, volar-dorsal width.

*Numbers represent mean (± SD).

There are limited data on the impact of the proximal hamate resection on wrist kinematics. Proximal hamate resection has been described for hamate arthrosis secondary to lunotriquetral ligament tears. A clinical study of 23 patients undergoing arthroscopic resection of 2 to 4 mm of the proximal pole of the hamate showed good results with 18 patients reporting minimal to no change in ability to work but 4 patients required further salvage surgery.²⁴ This was accompanied by a biomechanical cadaver study of 5 wrists that demonstrated no change in load across the triquetrohamate articulation with a 2.4-mm resection of the proximal hamate. However, the resection required for the proximal hamate osteochondral graft is much larger. In this study, the average resection was 9.3 mm with the smallest resection being 7.8 mm. Such large resections can cause destabilization of the triquetrohamate joint and midcarpal instability.^{15,25} In the case report by Elhassan et al,¹⁵ care was taken to ensure protection of the triquetrohamate ligament and the patient did not develop any dorsal intercalated segment instability at 3.5 years' follow-up. Longer term follow-up in a larger patient cohort will help to determine the impact of proximal hamate resection on remaining carpal stability and function.

Limitations of this study include the use of a cadaveric model with a mean specimen age of 70 years. Scaphoid fractures most commonly occur in young men in the third decade of life,^{26,27} and while cadaveric specimens were screened for history of carpal pathology, age-related radiocarpal and midcarpal degenerative changes are common²⁸ and can affect the shape of the scaphoid. Furthermore, the use of 3-dimensional computer modelling to simulate scaphoid proximal pole excision, and hamate autograft retrieval and inseting, represents another limitation. Although 3-dimensional reconstructions provide the ability to rotate and align the hamate with

the scaphoid prior to deciding the plane and angle of the desired osteotomy, performing the osteotomy during surgery presents greater challenges as the hamate remains in its anatomical orientation and position. As a result, a slightly larger hamate autograft may be required initially to be harvested to allow for further contouring once removed. Computer modelling also provides the luxury of algorithms to calculate the orientation of best fit. Future patient studies are required to evaluate studies are required to evaluate the technical feasibility and clinical outcomes of the proximal hamate osteochondral graft.

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