Quantitative 3D-CT Anatomy of Hamate Osteoarticular Autograft for Reconstruction of the Middle Phalanx Base

Paul Ten Berg MSc, David Ring MD, PhD

Received: 18 December 2011 / Accepted: 13 April 2012 / Published online: 27 April 2012
© The Association of Bone and Joint Surgeons® 2012

Abstract

Background Hamate osteoarticular autografts are difficult to obtain and it is unclear to what degree the graft matches the joint surface to be replaced and whether a direct ulnar approach might provide a more reliable graft than the standard proximal to distal approach.

Purpose We modeled hemihamate osteotomies using quantitative three-dimensional CT (3D-CT) to measure the amount of hamate articular surface used and the match with the native volar base of the middle phalanx.

Methods In virtual hemihamate osteotomies (standard and direct ulnar) on CTs of 20 patients (11 men and nine women), we measured the percentage of hamate articular surface used for each finger, the match of the articular contour, and the percentage of hamate articular surface removed.

Results The autograft in the standard approach used an average of 26% of the hamate articular surface and had an average 75% match of the articular contour with the volar half of the middle phalanx base. A direct ulnar approach removed an additional small margin of dorsal ulnar hamate with an average maximum width of 2.5 mm and volume of 27 mm³.

Conclusions An osteoarticular allograft from the hamate to replace the volar half of the middle phalanx base uses less than 1/3 of the hamate articular surface even if the dorsal ulnar margin of the hamate is taken with the graft.

Clinical Relevance These data suggest that it might be feasible to make the deep cut from a direct ulnar approach.

Each author certifies that he or she, or a member of their immediate family, has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.

All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research* editors and board members are on file with the publication and can be viewed on request.

Clinical Orthopaedics and Related Research neither advocates nor endorses the use of any treatment, drug, or device. Readers are encouraged to always seek additional information, including FDA-approval status, of any drug or device prior to clinical use. Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

This study was performed at Massachusetts General Hospital, Boston, MA, USA.

P. Ten Berg, D. Ring (✉)
Orthopaedic Hand and Upper Extremity Service, Harvard
Medical School, Massachusetts General Hospital,
Yawkey 2100, 55 Fruit St., Boston, MA 02114, USA
e-mail: dring@partners.org

P. Ten Berg
Academic Medical Centre, Amsterdam Zuidoost,
The Netherlands

Introduction

Capo et al. [3] suggested that an autogenous osteoarticular graft from the hamate could reconstruct the volar base of the proximal articular surface of the middle phalanx for unstable dorsal fracture-dislocations of the proximal interphalangeal (PIP) joint. Several case series [1, 2, 11] have documented the utility of this reconstructive procedure. The amount of hamate removed, the degree to which this varies according to the finger involved, and the match of the articular surfaces of the middle phalanx base and the hamate have not been determined.

Removing the hamate osteoarticular graft is technically difficult since the standard approach uses a cut that enters the articular surface either blind (from proximal to distal) or from inside the joint, which is difficult and can damage the

articular surface. Based on our clinical experience with the standard approach, with an appropriate graft size with the central ridge on center the ulnar sagittal (longitudinal) cut will come close to the ulnar edge of the hamate, which results in a relatively narrow ulnar margin. To better understand what part of the hamate is used for the graft, and with the hope of developing an easier method of removing an appropriately sized graft, we used quantitative three-dimensional (3D)-CT analysis techniques to measure the volumes and surface areas of the hamate graft and volar half of the middle phalanx base for the index through small fingers in men and women.

Our purposes were (1) to determine the amount of hamate articular surface used to reconstruct the volar half of the middle phalanx, (2) to measure the amount of dorsal ulnar hamate remaining after graft removal, and (3) to investigate the inclusion of this dorsal ulnar bone with the graft using a direct ulnar osteotomy.

Materials and Methods

From a list of CT scans of the wrist and hand provided by our radiology department, we selected 20 scans with a slice thickness of 0.62 mm that included the hamate and the entire PIP joint of the index through small fingers. We used scans from 11 men and nine women with a mean age of 43 years (SD, 17 years; range, 19–73 years). We limited the number to 20 because the analysis techniques are time and resource intensive. This protocol was approved by our Human Research Committee.

DICOM (Digital Imaging and Communications in Medicine) files were obtained through Vitrea (Vitrea 2 software; Vital Images, Minnetonka, MN, USA) and

exported for further processing into MATLAB (version 7.7; The MathWorks, Natick, MA, USA) and Rhinoceros (version 4.0; McNeel North America, Seattle, WA). This process, previously described by Guitton et al. [5], creates hollow 3D models from CT slices based on a wire model representing the outer margin of the cortical bone.

Using a software feature called surface angle analysis, angles within 30° of orthogonal to the metacarpal axis were determined. We measured the articular surface area of the hamate using a combination of this technique and overlapping of the ring and small metacarpals (Fig. 1).

We chose a graft length of 6 mm as it has been argued that this size is necessary for screw fixation [8] (Fig. 2). The central ridges of the middle phalanx base and the hamate were lined up in the orientation that the graft is used [11] (Fig. 3). After aligning the central ridges of the articular

Fig. 2 The volar base of the middle phalanx to be replaced by hamate autograft is defined as (1) 50% of the dorsal-volar height; (2) 6 mm length; (on the left side in lateral view), and (3) the width of the middle phalanx at this deep, distal edge of the graft 6 mm from the articular surface (label 1C) (on the right side in volar view).

Fig. 1A-C (A) Surface angle analysis provides an estimate of the hamate articular surface. The parts of the distal facing part of the hamate with a 60°- to 90°-angle to the anatomic axis are shown in red.

(B) The articular surface also can be defined by placing the ring and small metacarpals onto the hamate. (C) The total hamate articular surface is the well-bordered red area (mm²) (label 1A).

surfaces of the hamate and middle phalanx, the cuts were planned as described by Williams et al. [11]. The distance between the ulnar and radial sagittal cuts and the width of the axial (transverse) cut are based on the width of the middle phalanx (Fig. 4). The ulnar approach does not require the sagittal (longitudinal) cut at the ulnar side. In this approach, the coronal cut is prolonged through the whole ulnar side of the hamate and, therefore, not blind anymore (Fig. 5).

One author made all of the measurements of the hamate and each of the four PIP joints in three phases. In the first

Fig. 3 The central ridges are identified on both hollow models and act as reference points (articular surface is not shown for simplicity). After rotating and shifting the volar lip (yellow), the two central ridges are lined up.

phase we analyzed general characteristics of the volar half of the middle phalanx base and the hamate, which were essential for reconstruction of the graft and further analyses. In the second phase we analyzed the size and match of a hamate graft obtained in the standard approach that leaves part of the ulnar articular surface of the hamate intact. In the third phase we simulated the osteotomy by a direct ulnar approach and then analyzed the amount of hamate that would be lost if this approach were to be used.

In the first phase, the following measurements were made: (1A) The articular surface area of the hamate with the ring and small metacarpals (Fig. 1); (1B) the radial-ulnar width of the hamate at the level of the most proximal, deepest (volarmost) cut; (1C) the radial-ulnar width of the volar base of middle phalanx at the deep, distal edge of the graft situated at 50% of the dorsal-volar height and 6 mm distally from the articular surface (Fig. 2).

In the second phase, the following measurements were made: (2A, 2B) the amount of hamate articular surface removed after the traditional osteotomy (Fig. 4); (2C) the match of the middle phalanx and hamate articular surfaces estimated by measuring the volume of bone remaining (ie, shared volume) when the volar half of the middle phalanx base was subtracted from the dorsal hemihamate autograft articular surface. The congruence of articular surfaces was defined as the percent shared volume divided by the total shared and nonshared volumes directly underneath both articular surfaces. The nonshared volumes are the small parts that do not resemble and cover the shared volume that

Fig. 4 The left and middle sides show the dorsal hemihamate autograft removal in the standard regular approach and the articular surface of the graft (red; label 2A). The distance between the ulnar and radial sagittal cuts is based on the width of the middle phalanx (label 1C). On the right side, the congruence of articular surfaces is analyzed. To analyze the shared volume directly underneath the articular surfaces of the hemihamate autograft and the volar half of the middle phalanx base as a measure of the match of the articular

surfaces an axial cutting plane was made perpendicular to the axial plane of the graft at the dorsalmost part of the volar half of the middle phalanx base. From this plane distally the nonshared part of the hamate graft is red, the nonshared part of the volar half of the middle phalanx base is yellow, and the part of the volume below the articular surface shared by the hamate and volar half of middle phalanx is grey. The congruence of articular surfaces is defined as the percent shared volume divided by the total shared and nonshared volumes.

Fig. 5 The left and middle sides show the dorsal hemihamate autograft removal in the ulnar approach and the articular surface of the graft (red; label 3A). The overlap of the volar base of the middle phalanx (yellow) sized as a graft (see Fig. 2) was matched to the contour of the hamate articular surface (red) (similar to Fig. 4). The sagittal, coronal, and axial edges of the graft of the middle phalanx

base are shown as well. On the right side, in the volar and ulnar view, the amount of hamate on the ulnar side (the ulnar margin) that would be included with the graft in the ulnar approach is shown: the width of the volar proximal part of the ulnar margin (mm) (label 2D); the width of the volar distal (articular) part of the ulnar margin (mm) (label 2E); and the volume of the ulnar margin (mm^3) (label 2F).

Fig. 6 In a straight ulnar view on the deep coronal cut, shown as a one-dimensional line, via the ulnar approach and concomitant graft (yellow dorsal piece), the following measurements are done: the distance between the triquetrum and fifth metacarpal (mm) (label 3C); and the overlap of deep (most volar) cut by the metacarpal (mm) (label 3D).

is the general core shape (Fig. 4); and (2D, 2E, 2F) the width and volume of the ulnar margin of the dorsal hamate that remains after the graft has been removed (Fig. 5).

In the third phase, the following measurements were made: (3A, 3B) The percentage of hamate articular surface removed with additional removal of the dorsal ulnar margin of the hamate (Fig. 5); and (3C, 3D, 3E) the degree to which the small finger metacarpal and the triquetrum overlap or obscure the coronal (volarmost) cut in a direct ulnar view in which the coronal (volarmost) cut is a one-dimensional line (ie, the height of the cut) (Fig. 6).

Results

Using the standard approach, an osteoarticular autograft from the hamate articular surface with the ring and small metacarpals that would replace the volar articular lip of the

middle phalanx at the PIP joint to a depth of 6 mm uses an average of 26% of the hamate articular surface (SD, 5.5%; range, 11%–37%). The match of the articular surface of the hamate and the middle phalanx (by shared volume) is 75% (SD, 5.9%; range, 57%–87%). The percentage of the hamate articular surface used for the graft and the match of the articular surface of the hamate and the middle phalanx are comparable between men (Table 1) and women (Table 2).

The ulnar margin of the dorsal hamate that remains after removal of an osteoarticular graft is narrow, with an average width at the volar proximal end of 2 mm (SD, 1.1; range, 0.0–4.9) and at the volar distal (articular) end of 2.9 mm (SD, 1.2; range, 0.0–6.5). The mean volume of this remaining bone is 27 mm^3 (SD, 14; range, 4.5–76). The average width of the entire hamate at the volarmost proximal cut is 16 mm (SD, 1.5; range, 13–20); and the average radial-ulnar width of the osteoarticular graft (similar to the radial-ulnar width of the volar base of middle phalanx) is 11 mm (SD, 1.6; range, 6.6–14).

In the direct ulnar approach with an additional ulnar margin removal, the percentage of the hamate articular surface used for the graft is incremented to 29% (SD, 5.5%; range, 15%–42%). An average of 24% (SD, 21%; range, 0%–99%) of a direct ulnar approach to making the deep (volarmost) osteotomy to remove the hamate graft is obscured by the base of the small finger metacarpal.

Discussion

Removing the hamate osteoarticular graft in the treatment of fracture-dislocations of the proximal interphalangeal joint is technically difficult. The standard approach uses a cut that enters the articular surface and is either made blind (from

Table 1. Measurements in 11 men

Measurements	Index	Long	Ring	Small
General measurements (Phase 1)				
Characteristics of the volar half of the middle phalanx base and the hamate				
(A) Total hamate articular surface (mm ²)	200 (± 27; 170–250)	200 (± 27; 170–250)	200 (± 27; 170–250)	200 (± 27; 170–250)
(B) Width of the entire hamate at the volar-most proximal cut (mm)	17 (± 1.6; 13–20)	16 (± 1.5; 13–19)	16 (± 1.7; 13–20)	16 (± 1.6; 14–20)
(C) Width of middle phalanx base (mm)	12 (± 0.80; 11–13)	13 (± 0.63; 12–14)	12 (± 0.51; 11–13)	9.2 (± 0.55; 8.0–10)
Measurements in the standard approach (Phase 2)				
Articular surface				
(A) Articular surface of graft (mm ²)	50 (± 6.1; 41–59)	62 (± 10; 52–87)	51 (± 5.4; 42–61)	38 (± 4.5; 28–44)
(B) Articular surface of graft as a percentage of the total hamate articular surface (%)	26 (± 2.9; 21–31)	32 (± 3.3; 28–37)	26 (± 3.6; 21–31)	19 (± 2.9; 16–26)
(C) Estimates of the match of middle phalanx and hamate articular surfaces				
Shared volume/(shared + nonshared volumes) (%)	72 (± 4.6; 65–79)	73 (± 5.8; 57–78)	78 (± 5.1; 66–84)	75 (± 7.3; 59–87)
Characteristics of the dorsal-ulnar part of the hamate that remains after graft removal				
(D) Width of the volar proximal part of the ulnar margin (mm)	2.2 (± 0.93; 0.62–4.1)	1.5 (± 0.90; 0.020–3.1)	2.1 (± 1.2; 0.00–3.7)	3.1 (± 0.99; 2.0–4.9)
(E) Width of the volar distal (articular) part of the ulnar margin (mm)	3.0 (± 0.91; 1.6–4.7)	2.3 (± 0.73; 1.1–3.6)	2.8 (± 0.99; 1.4–4.1)	4.0 (± 1.4; 2.1–6.5)
(F) Volume ulnar margin (mm ³)	21 (± 8.2; 8.0–38)	18 (± 7.6; 4.9–34)	24 (± 10; 13–50)	49 (± 14; 28–76)
Measurements in the ulnar approach (Phase 3)				
Articular surface				
(A) Articular surface of graft (mm ²)	57 (± 10; 45–77)	67 (± 14; 55–102)	56 (± 7.0; 45–66)	48 (± 8.5; 36–62)
(B) Articular surface of graft as a percentage of the total hamate articular surface (%)	29 (± 3.6; 24–37)	34 (± 4.7; 29–42)	29 (± 4.1; 23–37)	24 (± 4.5; 19–37)
Direct ulnar view (coronal cut seen as a one-dimensional line)				
(C) Distance between the triquetrum small finger metacarpal base (mm)	7.2 (± 2.3; 3.1–11)	6.9 (± 2.0; 4.4–11)	7.6 (± 1.9; 5.0–11)	7.4 (± 2.5; 5.0–12)
(D) Overlap of the coronal cut by metacarpal (mm)	1.9 (± 1.6; 0.0–6.0)	1.6 (± 1.5; 0.0–5.0)	1.5 (± 1.3; 0.0–4.4)	1.5 (± 1.6; 0.0–4.7)
(E) Percentage of the coronal cut not obstructed by the small finger metacarpal (%)	69 (± 27; 1–100)	73 (± 24; 18–100)	75 (± 24; 18–100)	76 (± 24; 25–100)

proximal to distal) or from inside the joint, which is difficult and can damage the articular surface. To analyze the consequences of graft removal on the remaining hamate bone and to investigate the deep cut from a direct ulnar approach, we used quantitative 3D-CT analysis techniques, which are well accepted [4–7, 10]. Our purposes were (1) to determine the amount of hamate articular surface used to reconstruct the volar half of the middle phalanx, (2) to measure the amount of dorsal ulnar hamate remaining after graft removal, and (3) to investigate the inclusion of this dorsal ulnar bone with the graft using a direct ulnar osteotomy, as to our knowledge these numbers have not been quantified.

We note limitations to our study. First, we had a limited number of hands. This therefore might be considered pilot work, although we think that the study questions were

addressed well by our sample because there was limited variation and we did not encounter any outliers. Second, we did not determine the reliability of the measurements between observers—both are consequences of the time and resources involved in creating these models. One of the most subjective aspects of the technique is matching the central ridges of the volar base of the middle phalanx and the dorsal hamate. However, our impression is that there is relatively little room for variation in the majority of the modeling technique. The variations in simulated osteotomy are likely much less than in an actual operative procedure. Third, we were unable to account for differences in the cartilage on the articular surfaces, but it is safe to assume that these are small and conform to the shape of the underlying bone.

Table 2. Measurements in nine women

Measurements	Index	Long	Ring	Small
General measurements (Phase 1)				
Characteristics of the volar half of the middle phalanx base and the hamate				
(A) Total hamate articular surface (mm ²)	180 (± 10; 160–200)	180 (± 10; 160–200)	180 (± 10; 160–200)	180 (± 10; 160–200)
(B) Width of the entire hamate at the volar-most proximal cut (mm)	16 (± 1.6; 13–18)	16 (± 1.9; 12–19)	16 (± 1.8; 13–19)	16 (± 1.9; 13–19)
(C) Width of middle phalanx base (mm)	11 (± 1.7; 7–12)	12 (± 0.8; 11–13)	11 (± 0.95; 10–13)	8.8 (± 0.84; 8.0–10)
Measurements in the standard approach (Phase 2)				
Articular surface				
(A) Articular surface of graft (mm ²)	46 (± 11; 21–61)	56 (± 5.1; 47–64)	49 (± 5.1; 43–60)	33 (± 5.7; 11–31)
(B) Articular surface of graft as a percentage of the total hamate articular surface (%)	26 (± 5.7; 11–31)	31 (± 2.4; 26–35)	27 (± 2.8; 23–31)	18 (± 2.2; 15–22)
(C) Estimates of the mismatch of middle phalanx and hamate articular surfaces				
By shared volume/(shared + nonshared volumes) (%)	77 (± 6.7; 67–85)	75 (± 5.6; 68–84)	76 (± 4.7; 69–84)	77 (± 5.5; 69–84)
Characteristics of the dorsal-ulnar part of the hamate that remains after graft removal				
(D) Width of the volar proximal part of the ulnar margin (mm)	1.7 (± 1.0; 0.0–3.0)	0.85 (± 0.71; 0.0–2.1)	1.5 (± 0.79; 0.56–2.7)	2.7 (± 0.90; 1.7–4.4)
(E) Width of the volar distal (articular) part of the ulnar margin (mm)	2.8 (± 0.78; 1.3–3.7)	2.0 (± 1.0; 0.0–3.4)	2.9 (± 1.2; 0.0–4.4)	3.7 (± 1.0; 1.7–5.7)
(F) Volume ulnar margin (mm ³)	21 (± 8.8; 8.7–37)	15 (± 7.7; 4.5–26)	26 (± 10; 7.6–38)	36 (± 13; 15–56)
Measurements in the ulnar approach (Phase 3)				
Articular surface				
(A) Articular surface of graft (mm ²)	51 (± 10; 27–64)	60 (± 5.0; 51–67)	55 (± 4.3; 47–60)	40 (± 5.3; 30–47)
(B) Articular surface of graft as a percentage of the total hamate articular surface (%)	28 (± 5.5; 15–34)	34 (± 2.8; 29–37)	31 (± 3.4; 26–36)	22 (± 3.0; 17–27)
Direct ulnar view (coronal cut seen as a one-dimensional line)				
(C) Distance between the triquetrum small finger metacarpal base (mm)	7.5 (± 2.3; 3.6–9.8)	6.9 (± 2.0; 3.1–9.4)	7.3 (± 1.8; 4.2–9.4)	8.2 (± 2.3; 5.1–12)
(D) Overlap of the coronal cut by metacarpal (mm)	1.4 (± 1.0; 0.0–3.1)	1.3 (± 1.1; 0.0–2.7)	1.1 (± 1.0; 0.0–2.9)	1.1 (± 1.1; 0.0–2.9)
(E) Percentage of the coronal cut not obstructed by the small finger metacarpal (%)	77 (± 18; 47–100)	78 (± 18; 54–100)	82 (± 17; 53–100)	82 (± 19; 51–100)

By creating virtual hemihamate osteotomies in a traditional approach in 3D-computer simulation, we estimated that an osteoarticular autograft from the dorsal hamate sized to replace the volar half of the base of the middle phalanx uses just greater than 1/4 of the total hamate articular surface on average. We estimated the match of the hamate articular surface with the middle phalanx base by measuring nonshared volumes and found the match to be approximately 75% on average with wide ranges but relatively little variation in the means by specific finger and between sexes. Based on reported clinical experience with the graft [1, 2, 11], this amount of mismatch seems relatively inconsequential. It seems more important to restore a volar lip than that it have a

precise match. Capo et al. [3] evaluated in a cadaveric study with eight fresh-frozen cadaveric hands, the hamate osteoarticular autograft for proximal interphalangeal joint fracture dislocations of digits 2 through 5. Assessment with a loupe magnification (3.5×) confirmed anatomic alignment of the bicondylar facets and central ridge of the hamate graft with the middle phalanx and no appreciable step-off of the chondral surfaces. In all cases, AP and lateral radiographs showed congruent joint reduction and less than 0.5 mm articular step-off.

An osteoarticular autograft from the dorsal hamate sized to replace the volar half of the base of the middle phalanx leaves a relatively small ulnar margin of remaining dorsal

hamate in the standard approach. In the study of Capo et al. [3], the ulnar and radial margins were mentioned, but analyses of the dimensions were absent. However, the radial-ulnar widths of the entire hamate and of the volar base of the middle phalanx were measured: 16 mm and 11 mm respectively. These average and rounded values are similar to ours.

In the 3D-computer simulation we explored the feasibility of the deep (volar) osteotomy from a direct ulnar direction. Less than 1/4 of the deep cut is obscured by the overhanging base of the small finger metacarpal in this direct ulnar view. The relatively large space between the base of the fifth metacarpal and the triquetrum may allow adequate access for a direct ulnar cut, but additional study is needed. Making the deep cut on the ulnar aspect of the hamate heading from ulnar to radial might improve observation and control over the standard approach of proximal to distal blind osteotomy or a distal to proximal cut starting in the joint. Future studies will address these factors and if any ligaments would be injured with an ulnar approach. A 3D analysis of the ligamentous attachments of the carpometacarpal joints [9] shows the position of a dorsal fifth metacarpal ulnar base-hamate ligament which could attach at the ulnar margin. In the ulnar approach with an additional ulnar margin removal, the percentage of the hamate articular surface used for the graft increases an average of only 3%.

Our study showed a potential for simulating operative procedures using quantitative 3D-CT models that allow for quantitative measurements. The ability to observe and measure the small amount of ulnar bone remaining in the dorsal part of the hamate improved our understanding of the graft and suggested other options for improving the facility and accuracy of osteotomy to obtain the graft. However, this proposed direct ulnar approach cannot be recommended until additional anatomic and biomechanical

studies confirm that it does not destabilize the articulation between the hamate and small finger metacarpal.

References

1. Afendras G, Abramo A, Mrkonjic A, Geijer M, Kopylov P, Tagil M. Hemi-hamate osteochondral transplantation in proximal interphalangeal dorsal fracture dislocations: a minimum 4 year follow-up in eight patients. *J Hand Surg Eur Vol.* 2010;35:627–631.
2. Calfee RP, Kiefhaber TR, Sommerkamp TG, Stern PJ. Hemi-hamate arthroplasty provides functional reconstruction of acute and chronic proximal interphalangeal fracture-dislocations. *J Hand Surg Am.* 2009;34:1232–1241.
3. Capo JT, Hastings H 2nd, Choung E, Kinchelow T, Rossy W, Steinberg B. Hemicondylar hamate replacement arthroplasty for proximal interphalangeal joint fracture dislocations: an assessment of graft suitability. *J Hand Surg Am.* 2008;33:733–739.
4. Guitton TG, Ring D. Three-dimensional computed tomographic imaging and modeling in the upper extremity. *Hand Clin.* 2010;26:447–453, viii.
5. Guitton TG, van der Werf HJ, Ring D. Quantitative measurements of the volume and surface area of the radial head. *J Hand Surg Am.* 2010;35:457–463.
6. Guitton TG, van der Werf HJ, Ring D. Quantitative three-dimensional computed tomography measurement of radial head fractures. *J Shoulder Elbow Surg.* 2010;19:973–977.
7. Guitton TG, Van Der Werf HJ, Ring D. Quantitative measurements of the coronoid in healthy adult patients. *J Hand Surg Am.* 2011;36:232–237.
8. McAuliffe JA. Hemi-hamate autograft for the treatment of unstable dorsal fracture dislocation of the proximal interphalangeal joint. *J Hand Surg Am.* 2009;34:1890–1894.
9. Nanno M, Buford WL Jr, Patterson RM, Andersen CR, Viegas SF. Three-dimensional analysis of the ligamentous attachments of the second through fifth carpometacarpal joints. *Clin Anat.* 2007;20:530–544.
10. van Leeuwen DH, Guitton TG, Lambers K, Ring D. Quantitative measurement of radial head fracture location. *J Shoulder Elbow Surg.* 2011 Nov 8. [Epub ahead of print].
11. Williams RM, Kiefhaber TR, Sommerkamp TG, Stern PJ. Treatment of unstable dorsal proximal interphalangeal fracture/dislocations using a hemi-hamate autograft. *J Hand Surg Am.* 2003;28:856–865.