# Morphometric analysis of potential osteochondral autografts for resurfacing unicondylar defects of the proximal phalanx in PIP joint injuries.

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# Morphometric Analysis of Potential Osteochondral Autografts for Resurfacing Unicondylar Defects of the Proximal Phalanx in PIP Joint Injuries

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**Purpose** This study was designed to morphometrically assess the base of the little and ring finger metacarpals as potential osteochondral donors to resurface distal condylar defects of the proximal phalanx.

**Methods** The proximal phalanges were dissected from all 4 fingers in 10 cadaveric hands and the following measurements were obtained from the distal condylar surface: anteroposterior height, radial-ulnar width, and radius of curvature. Measurements were obtained from posteroanterior and lateral radiographic views, which were digitized and analyzed using digital imaging software. Comparable measurements were obtained from the base of the small and ring metacarpals.

**Results** The anteroposterior dimension of both potential donor metacarpals was large enough to resurface the distal condyles of each of the proximal phalanges; however, this was not true for the radial-ulnar dimensions. The distal ulnar condyle of the long finger proximal phalanx was largest, measuring 4.9 (± 0.) mm dorsally and 6.2 (± 0.5) mm volarly in the radial-ulnar dimension. Only the small metacarpal base had sufficient stock in the radial-ulnar dimension (9.4 [± 1.7]) mm dorsally and 10.6 [± 2.0] mm volarly) to resurface this condyle. With respect to radius of curvature (ROC), the donor-to-recipient ROC ratio was 1.43 for the small metacarpal base versus 2.12 for the ring metacarpal base. Linear regression analysis revealed a stronger relationship in ROC between donor and recipient condyle when the small metacarpal base served as the donor (R = 0.96 vs R = 0.60).

**Conclusions** As determined from morphometric measurements of the 2 potential donor sites tested, the base of the small metacarpal provides the best match for resurfacing distal condylar defects of the proximal phalanges. *(J Hand Surg 2010;35A:604–610. Copyright © 2010 by the American Society for Surgery of the Hand. All rights reserved.)*

**Key words** Osteochondral arthroplasty, proximal phalanx unicondyle fracture, proximal interphalangeal joint injury.

TREATMENT OF SEVERE condylar injuries of the proximal interphalangeal joint, including acute comminuted fractures and malunion with post-traumatic degenerative changes, is a challenging problem. Current treatment options include osteosynthesis for acute fractures,[1] corrective osteotomy for malunions,[2] arthrodesis,[3] implant arthroplasty,[4,5] osteochondral grafts (partial articular allograft or osteochondral autograft),[6–10] and vascularized joint transfers.[11–14]

Young patients with unreconstructable defects and desiring motion have few options, however, because implants are not durable and osteochondral allograft

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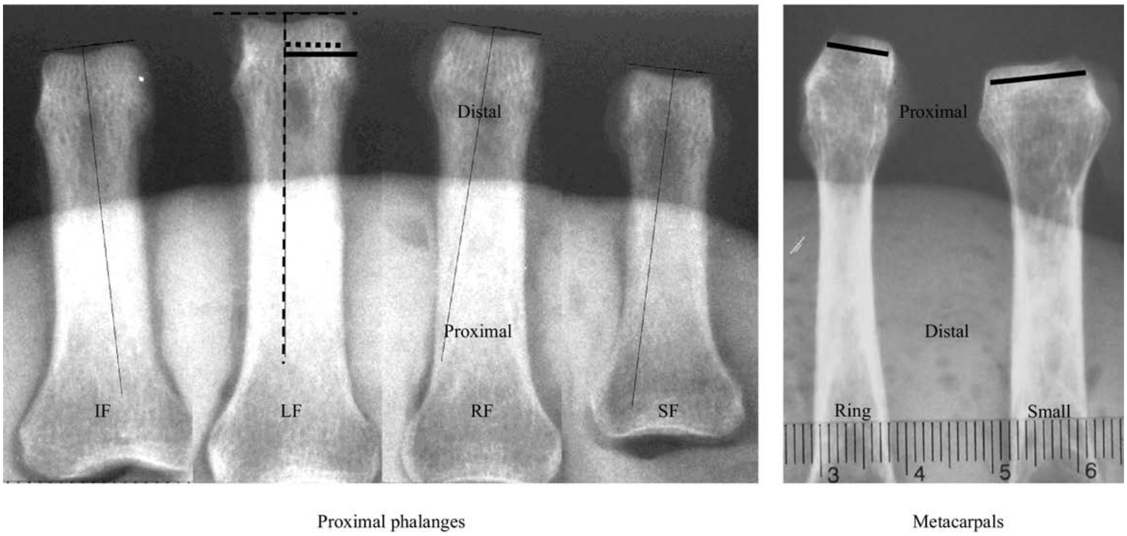


**FIGURE 1:** Posteroanterior radiographic views of the proximal phalanges and metacarpals from a single specimen, demonstrating measurement of radioulnar width. For the distal end of the phalanges, a line perpendicular to the distal condylar surfaces was drawn through the center of the intercondylar notch (dashed line). The width of each condyle was measured, using the distance from the perpendicular line to the radiographic silhouette of the volar (solid line) and dorsal (dashed line) surfaces for each condyle. The proximal end of the metacarpals was catalogued with respect to the full radioulnar dimension.

reconstruction can result in early osteoarthritis. Vascularized joint transfer[11–14] and rib perichondral autograft[7,10] are potential biological solutions. However, vascularized toe joint transfer is a complex microvascular procedure that results in donor site morbidity, and full range of motion is rarely restored. Although costal osteochondral autograft has less morbidity, satisfactory range of motion and satisfactory long-term outcome is questionable.[10]

We undertook the present anatomical dissection study to determine whether osteochondral autograft obtained from the proximal surface of the ring or small finger metacarpal could be used as an alternative to resurface distal condyle defects of the proximal phalanx. A previous report demonstrated that the distal, concave, articular surface of the hamate could be successfully used to resurface the base of the middle phalanx in dorsal proximal interphalangeal fracture–dislocations.[15] This graft is easily harvested and results in minimal morbidity. Therefore, our hypothesis is that the opposing joint surfaces to the hamate—that is, the convex small or ring metacarpal bases—can be used as an osteochondral autograft to resurface unicondylar defects of the distal end of the proximal phalanx.

This study uses morphometric analysis to compare anatomic parameters of the proximal phalangeal condyles to the small and ring metacarpal bases in order to determine the most suitable donor for proximal phalangeal unicondylar reconstruction. Morphometric analysis is a precise and efficient method whereby tissue is quantified digitally with the aid of a computer.

## MATERIALS AND METHODS

### Anatomical measurements

Ten fresh-frozen cadaveric hands were thawed and dissected to harvest the metacarpals and the proximal phalanges. The anteroposterior (AP; height), radial-ulnar (width), and radius of curvature (ROC) dimensions of the heads of the index, middle, ring and small finger proximal phalanges and the bases of the ring and small metacarpals were measured from posteroanterior (PA) and lateral radiographic views.

To ensure proper orientation of the harvested specimens, each bone was embedded in clay, each radiograph was obtained with the specimen lying directly on the cassette to prevent image magnification, and each radiograph was inspected before measurement. Radiographs were digitally photographed and calibrated and measurements were made from the digitized radiographs using digital imaging software (ImageJ; National Institutes of Health, Bethesda, MD).

Posteroanterior radiographs were used to measure radioulnar width. The volar width of the distal condyles of the proximal phalanx is greater than the dorsal width, which was easily observed on the PA radiographs (Fig. 1).

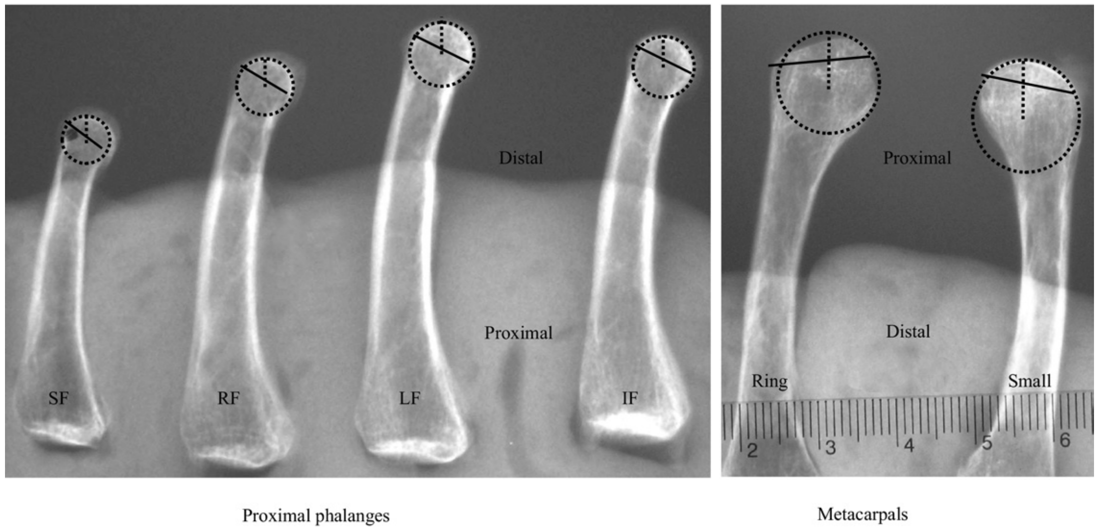


**FIGURE 2:** Lateral radiographic views of the proximal phalanges and metacarpals from a single specimen, demonstrating measurement of ROC and AP height. For the distal end of the phalanges and the proximal end of the metacarpals, height was measured using a drawn line, obtaining the maximum distance from the anterior to posterior distance of the articular surface (solid lines). The ROC was obtained by calculating the radius from a circle of best fit to the articular surfaces. For the condyles of the proximal phalanges, 2 distinct silhouettes of the condyles were seen in profile. Each condyle was measured, and measurements were assigned to the appropriate condyle (radial vs ulnar), as determined by direct specimen examination.

The width of each condyle was measured, using the distance from a line drawn perpendicular to the distal condylar surfaces through the center of the intercondylar notch to the radiographic silhouette of the volar and dorsal surfaces for each condyle. Measurements for the proximal end of the MCs were obtained using the full radioulnar dimension.

Lateral radiographs were used to obtain AP height and ROC. The silhouettes of both condyles of the proximal phalanx were readily identified in profile (Fig. 2). The ROC was defined by determining a "circle of best fit" to each condylar silhouette and then calculating the radius. The AP height was measured by a drawn line, obtaining the maximum distance from the anterior to posterior distance of the articular surface. Measurements obtained radiographically were assigned to the appropriate condyle post hoc, as determined by direct examination of the specimen. Obtaining ROC and AP height for the base of the ring and small finger metacarpals was performed in a similar, but less complex, manner because the base is essentially unicondylar.

Three measurements were obtained for each specimen and dimension, and the average was used for statistical comparison. The various condylar dimensions were compared within and between digits and to similar dimensions of the MC bases.

### Statistical analysis

Linear regression analysis was used to establish a correlation in ROC between the donor MC bases and recipient condyles for the purpose of determining the donor with the more consistent relationship.

## RESULTS

### Morphometry

Anteroposterior, radial-ulnar, and ROC dimensions for the index through little proximal phalangeal condyles and the little and ring metacarpal bases are shown in Table 1. The radial condylar dimensions were greater than the ulnar condylar dimensions for the ring and small fingers. The opposite was found for the index and long fingers. The largest condyle measured was the ulnar condyle of the long finger, and the smallest was the ulnar condyle of the small finger.

The anatomic dimensions of the small and ring metacarpal bases were compared to those of the proximal phalangeal condyles of the index through small fingers to determine whether adequate osteochondral material was available in the potential donors. Figure 3 demonstrates that both the small and ring metacarpals have adequate material in the AP dimension. The AP dimensions of the small and ring metacarpal bases were 9.6 (± 1.7) mm and 11.2 (± 1.16) mm, respectively. The smallest condyle measured 6.3 (± 0.5) mm and the

**TABLE 1. Measured Dimensions**

| Specimen | AP Height (mm) | Dorsal Radial-Ulnar Width (mm) | Volar Radial-Ulnar Width (mm) | ROC (mm) |
|---|---|---|---|---|
| P1 Index | | | | |
| Radial condyle | 7.5 ± 0.7 | 3.9 ± 0.3 | 5.1 ± 0.6 | 3.8 ± 0.3 |
| Ulnar condyle | 8.3 ± 0.7 | 4.8 ± 0.3 | 5.8 ± 0.2 | 4.1 ± 0.4 |
| P1 Long | | | | |
| Radial condyle | 7.8 ± 0.7 | 4.1 ± 0.3 | 5.3 ± 0.5 | 3.9 ± 0.3 |
| Ulnar condyle | 8.3 ± 0.6 | 4.9 ± 0.4 | 6.2 ± 0.5 | 4.2 ± 0.3 |
| Metacarpal | | | | |
| Small | 9.6 ± 1.7 | 9.4 ± 1.7 | 10.6 ± 2.0 | 5.3 ± 0.7 |
| Ring | 11.2 ± 1.11 | 8.5 ± 1.1 | 5.7 ± 1.2 | 7.8 ± 2.1 |
| P1 Ring | | | | |
| Radial condyle | 7.6 ± 0.6 | 4.4 ± 0.3 | 5.5 ± 0.4 | 3.8 ± 0.3 |
| Ulnar condyle | 7.3 ± 0.6 | 3.9 ± 0.5 | 5.0 ± 0.6 | 3.7 ± 0.3 |
| P1 Small | | | | |
| Radial condyle | 6.7 ± 0.5 | 3.9 ± 0.3 | 5.0 ± 0.5 | 3.4 ± 0.3 |
| Ulnar condyle | 6.3 ± 0.5 | 3.2 ± 0.5 | 4.2 ± 0.5 | 3.2 ± 0.2 |

P1, proximal phalanges. Average values ± standard deviation.

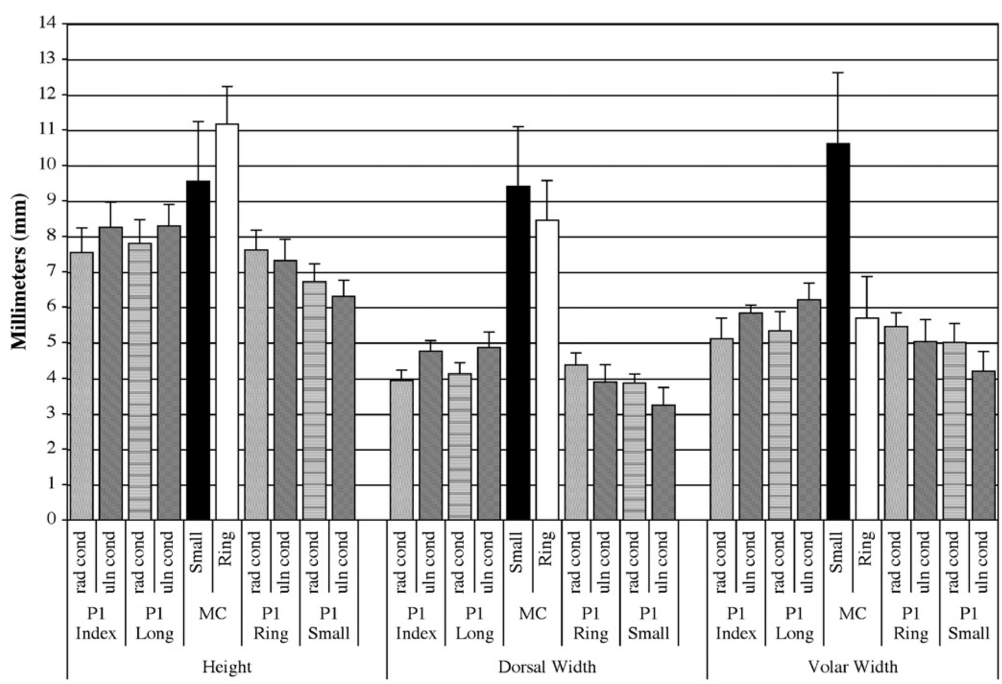


**FIGURE 3:** Histogram demonstrating AP condylar height, dorsal radial-ulnar width, and volar radial-ulnar width for the proximal phalangeal condyles of the index through small fingers and for the ring and small MC bases.

largest condyle measured 8.3 (± 0.6) mm in the AP dimension. The radial-ulnar dimensions of the small metacarpal base were 9.4 (± 1.7) mm dorsally and 10.6 (± 2.0) mm volarly, whereas the ring metacarpal base measured 8.5 (± 1.1) mm dorsally and 5.7 (± 1.2) mm volarly. The largest condyle measured 4.9 (± 0.4) mm dorsally and 6.2 (± 0.5) mm volarly in the radial-ulnar dimension. Thus only the small metacarpal base dem-

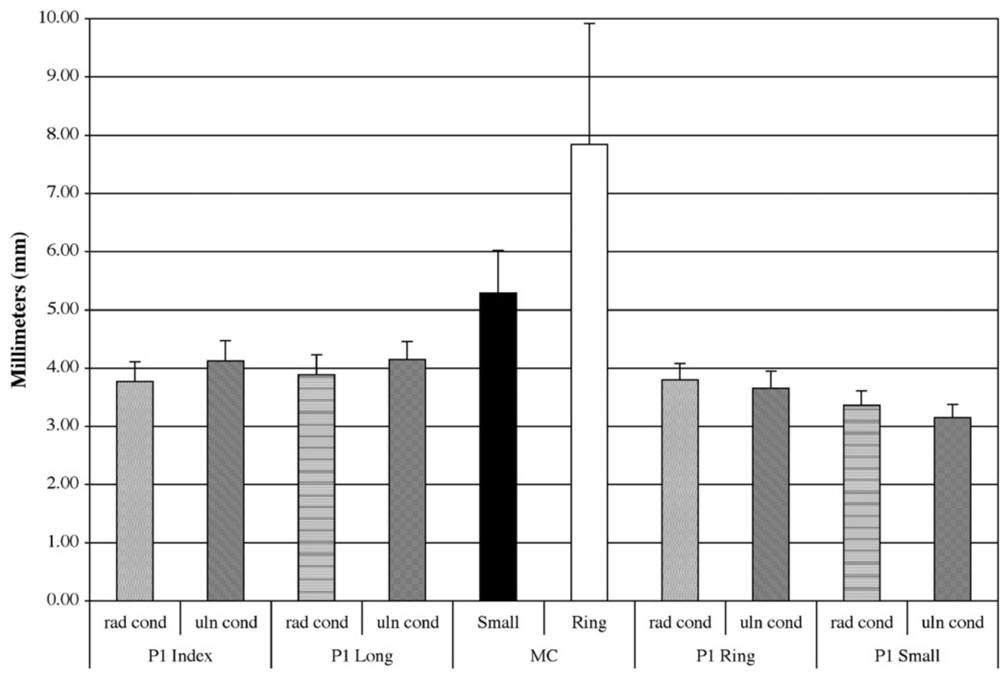


**FIGURE 4:** The ROC for the proximal phalangeal condyles of the index through small fingers and for the small and ring metacarpal bases.

onstrated adequate donor material to reconstruct all the phalangeal condyles in the radio-ulnar dimension.

Figure 4 shows that the ROC for both potential donor grafts is greater than that for all the recipient condyles. The ROC measured 5.3 (± 0.7) mm and 7.8 (± 2.1) for the small and ring metacarpal bases, respectively. The largest and smallest condyle measured 4.2 (± 0.3) and 3.2 (± 0.2) mm, respectively. The ideal ratio between recipient and donor with respect to ROC is 1.0. The average ROC ratio of the ring metacarpal base to the distal condyle of the proximal phalanx is 2.1, compared to 1.4 for the small metacarpal base. The specific ROC ratios for each metacarpal base to each condyle are shown in Table 2.

**TABLE 2. Radius of Curvature Ratios**

| Recipient | Donor Metacarpal, Small | Donor Metacarpal, Ring |
|---|---|---|
| P1 Index | | |
| Radial condyle | 1.4 | 2.1 |
| Ulnar condyle | 1.3 | 1.9 |
| P1 Long | | |
| Radial condyle | 1.4 | 2.0 |
| Ulnar condyle | 1.3 | 1.9 |
| P1 Ring | | |
| Radial condyle | 1.4 | 2.1 |
| Ulnar condyle | 1.5 | 2.2 |
| P1 Small | | |
| Radial condyle | 1.6 | 2.3 |
| Ulnar condyle | 1.7 | 2.5 |
| Average | 1.4 | 2.1 |

P1, proximal phalanges. The ROC ratio is the ratio in donor to recipient ROC. The ideal ratio is 1.0. The average ratio is computed for both potential donors.

### Regression analysis

Regression analysis was used to determine whether the relationship between donor and recipient ROC remains constant among various hand sizes (Fig. 5). The regression coefficient (R) for the ring metacarpal base is 0.6 and for the small metacarpal base, $R = 0.96$ A perfect correlation is indicated by an R value of 1.0.

The slope of the regression line represents the calculated ROC ratio. These values are 3.0 for the ring metacarpal base and 1.6 for the little metacarpal base.

## DISCUSSION

In this investigation, the base of the small and ring finger metacarpals were morphometrically assessed as potential donors to replace 1 of the condyles of the proximal phalanx. Of the 2 potential donor grafts investigated, only the small metacarpal base demonstrated adequate graft material to resurface all dimensions of the largest phalangeal condyles. Both potential donors demonstrated adequate graft in the AP and dor-

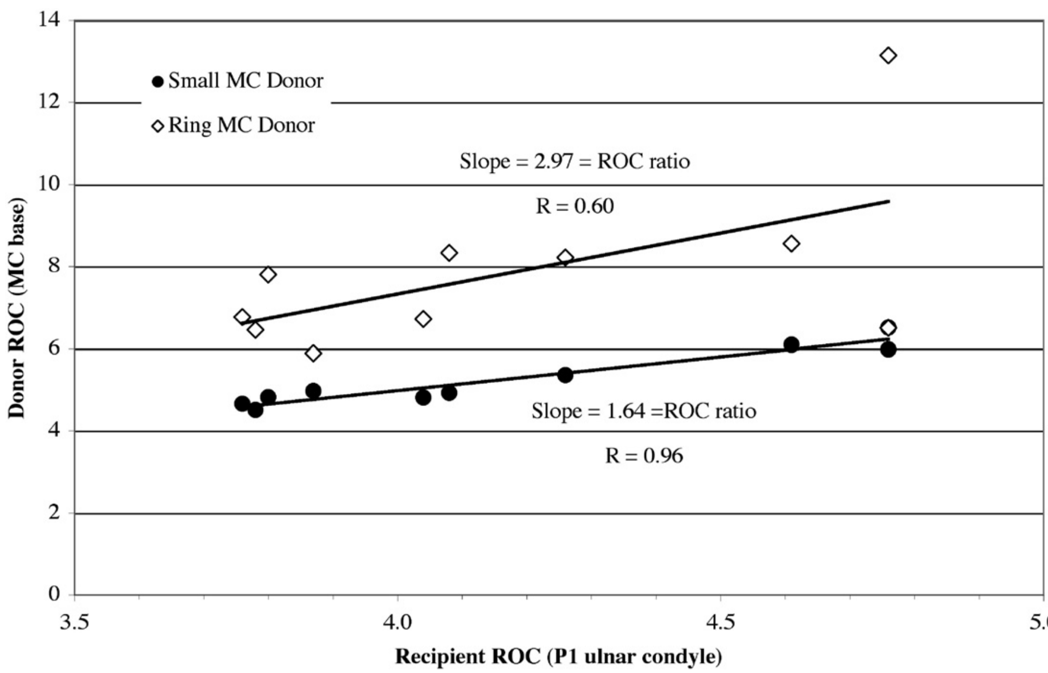


**FIGURE 5:** Linear regression analysis. Scatter plot demonstrating the relationship in ROC between the donor MC bases and the recipient condyle. In this scatter plot, the ROC for the ring (open diamonds) and small (closed circles) metacarpal bases are shown as a function of the ROC for the ulnar condyle of the index proximal phalanx (P1). Linear regression was applied to the data to determine the strength of correlation between the variables. The slope of the regression line represents the calculated ROC ratio. Regression coefficients (R) are shown.

sal radial-ulnar dimensions. When assessing volar width, however, only the little metacarpal had adequate osteocartilaginous stock to allow for adjustments. The ring metacarpal base, on the other hand, had just enough material, which provides minimal room for error in making adjustments in the volar dimension. In addition, harvesting the entire volar surface could cause ring carpometacarpal (CMC) instability. These would not be concerns for the small metacarpal base, because there is adequate material in all dimensions.

Although the ring metacarpal base has enough stock to reconstruct some of the condyles, its large ROC makes it less suited for condylar reconstruction. The small metacarpal base, on the other hand, has a lower ROC that more closely approximates that of the phalangeal condyles. In addition, regression analysis demonstrates that the relationship in ROC between donor and recipient is stronger for the little metacarpal base, indicating that the correlation between donor and recipient will remain a constant, despite variation in hand size.

Anatomically, the phalangeal condyles flare volarly and laterally, thus making the condyles oblique to the lateral projection. The ROC of the phalangeal condyles was measured from lateral radiographic projections in this study. Thus, the phalangeal condyle ROC is likely underestimated by our measurements, although we do not think the amount of this underestimation is important. Nonetheless, the ROC of the small metacarpal base might approximate the ROC of the phalangeal condyles more closely than the data in the present study would indicate.

Both the ulnar and the radial base of the small metacarpal can be used; however, the ulnar base is conceptually simpler to harvest. The radial base is bordered by the ring metacarpal base, which would make it more difficult to harvest. The ulnar base can be used to resurface either the radial or the ulnar condyle after being rotated appropriately.

In the ulnar 2 digits, the radial condyle is more frequently fractured than the ulnar condyle.[1] The opposite occurs for the radial 2 digits; that is, the ulnar condyle is more frequently fractured than the radial condyle. The condyles that are frequently fractured also happen to be the larger condyles by measurements obtained in the present study. Given that the small finger metacarpal graft has a larger radius of curvature than any of the condyles, those condyles that are frequently damaged are a better match for the small metacarpal donor graft.

Development of osteoarthritis and instability at the donor site are legitimate concerns following harvest.

Although it remains to be determined whether donor site morbidity will occur following partial osteochondral harvest of the small metacarpal base, a recent report on hemi-hamate harvests by Williams et al[15] revealed no donor site morbidity at the CMC joint. Because only a portion of the small metacarpal base is needed for resurfacing condylar defects, we expect little or no donor site morbidity at the CMC joint following graft harvest. However, only clinical evaluation can determine if CMC instability occurs following osteochondral harvest.

Another concern following autograft reconstruction is the viability of the osteochondral graft. In the same study, Williams et al[15] demonstrated graft survivability in all patients treated with distal hamate osteochondral grafting for dorsal proximal interphalangeal fracture–dislocations.[15] This is consistent with studies examining unicondylar grafts.[6,7] However, using grafts to reconstruct both condyles has been met with less success.[8]

The present study has demonstrated that the base of the small metacarpal is of appropriate dimensions to be suited for osteochondral donor material to resurface the proximal phalangeal condyles. We believe that the base of the small metacarpal would compare favorably with previously used autografts for condylar reconstruction,[6–9] and conceptually should be simple to harvest.

The presumptive indications for reconstructing unicondylar defects of the proximal interphalangeal joint using the ulnar base of the small metacarpal include both acute and chronic conditions. In the acute situation, it is conceivable that osteochondral resurfacing can be used for severely comminuted condyle fractures with an unreconstructable articular surface. It could also be used in chronic situations in which malunion of the condyle fracture is associated with posttraumatic osteoarthritis, excessive bone stock resorption, or malrotation. A clinical study addressing the applicability of osteochondral resurfacing of unicondylar defects (condylar replacement arthroplasty) is currently underway.

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