BASIC SCIENCE

Three-dimensional suitability assessment of three types of osteochondral autograft for ulnar coronoid process reconstruction

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Background: Osteochondral autografts with use of the olecranon tip, lateral radial head, or proximal radial head have been employed for coronoid process reconstruction. However, it is unclear which autograft is most suitable for coronoid articular configuration. We assessed 3-dimensional articular facet suitability of 3 osteochondral autografts for coronoid process reconstruction.

Methods: We performed 3-dimensional computed tomography of 20 elbows to compare the articular facet configuration between the coronoid process and the ipsilateral olecranon tip, lateral radial head, and proximal radial head. We measured the area of the proximity region (≤2.0 mm) between the articular facets of the coronoid process and 3 osteochondral autografts, the covering rate defined as the percentage area of the coronoid articular facet occupied by the proximity region, the location of the proximity region center, and the percentage of the removed ulnohumeral articular facet.

Results: The covering rate was significantly higher with an olecranon graft than with radial head grafts. The regional center of a proximal radial head graft was significantly medial compared with that of olecranon and lateral radial head grafts. The olecranon graft used an average of 13.8% of the ulnohumeral articular facet.

Conclusions: An olecranon graft was most suitable for defects of the coronoid process involving the tip, and a proximal radial head graft was most suitable for defects of the coronoid process involving the anteromedial rim. The use of an olecranon graft for reconstruction of 50% of the height of the coronoid process does not cause concern for gross elbow instability.

Level of evidence: Level III, Diagnostic Study.
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Keywords: Coronal process; olecranon graft; radial head graft; three-dimensional analysis; reconstruction

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Surgical treatment of persistent posterior elbow dislocation after comminuted fractures of the coronoid process is challenging. When the loss of the coronoid process causes elbow dislocation and instability, coronoid process reconstruction with autografts should be considered. Autografts...
have been harvested from the radial head, olecranon, iliac crest bone, tibia, and distal humerus. The radial head and olecranon have especially been used as osteochondral bone grafts and are more beneficial than a simple bone graft without cartilage. Moritomo et al. used the ipsilateral olecranon tip as an osteochondral autograft to reconstruct the coronoid process in patients with persistent elbow dislocation. van Riet et al. described use of the lateral articular facet of the radial head, and Ring et al. used the proximal articular facet of the radial head. However, it is unknown which of these osteochondral grafts is most suitable as a substitute for coronoid articular configuration.

The coronoid articular facet articulates with the trochlea of the humerus and has a convex lateral surface and concave medial surface. The convex surface appears to match the articular facet of the olecranon and the lateral facet of the radial head, whereas the concave surface matches the proximal facet of the radial head. Because of the differences in the shapes of the olecranon, coronoid, and radial head, the portion that each graft can reconstruct on the coronoid articular facet may differ.

Although a radial head graft is often harvested from the discarded fragment followed by a radial head arthroplasty to reconstruct the coronoid process, the olecranon graft is harvested from the ipsilateral olecranon tip without reconstruction of the olecranon tip. Therefore, the consequences of olecranon resection need to be considered. Some biomechanical studies have concluded that the extent of olecranon resection influences elbow stability. However, the extent of olecranon resection required for coronoid process reconstruction remains unknown.

We hypothesized that the olecranon graft would be most suitable for defects of the coronoid process including the tip without causing gross instability. This study aimed to evaluate the suitability of 3 osteochondral grafts by measuring the area and location of the proximity region between the normal and reconstructed articular facets of the coronoid process and to measure the percentage of the ulnohumeral articular facet of the ulna occupied by the resected olecranon articular facet.

### Materials and methods

We studied 20 forearms (8 right and 12 left) in 20 subjects (10 women and 10 men; mean age, 37 years; range, 16-66 years). All subjects initially presented to our hospital with contralateral forearm disorders, such as upper extremity fracture malunions, ulnocarpal impaction syndrome, or distal radioulnar joint instability. We used only computed tomography (CT) data from the normal side in this study, although we performed bilateral CT scans for comparison.

Both forearms, from elbow to wrist, were scanned by CT (helical CT, LightSpeed Ultra16; General Electric, Waukesha, WI, USA; slice thickness, 1.25 mm). Data were saved in the Digital Imaging and Communications in Medicine format and sent to a computer. We transferred the digital data to Bone Viewer (Orthree, Osaka, Japan), extracted regions of the radius and ulna in all slice images semiautomatically by segmentation, created 3-dimensional (3D) models of the radius and ulna, and visualized these images with Bone Simulator (Orthree, Osaka, Japan). The previous accuracy analysis of 3D bone models, which was constructed from CT data with 0.625-mm thickness by use of our original computer program, showed that the mean error was 0.45 mm.

The cutting plane of the coronoid process was defined as a plane parallel to the posterior flat spot on the olecranon and at 50% of the height of the coronoid process (Fig. 3). The coronoid region was defined as the anterior part of the ulnohumeral articular facet of the original ulna divided by the cutting plane.

We simulated 3 different osteochondral autografts: olecranon, lateral radial head, and proximal radial head. For the olecranon graft, a second ulna model was duplicated from the original, and the olecranon tip of the duplicated model was flipped around and superimposed on the corresponding part of the coronoid process of the original model (Fig. 4, A). For the lateral and proximal radial head grafts, the lateral and proximal sides of the articular facets of the radial head were respectively superimposed on the corresponding part of the coronoid process (Fig. 4, B, C). We investigated the proximity region with a distance of ≤2.0 mm between the articular surfaces of the coronoid region and the grafts by a proximity mapping method (Fig. 5). The articular facet area was calculated by selecting all individual surface triangles with use of Magics RP (Materialise, Leuven, Belgium). The covering rate was calculated by the following equation:

$$\text{Covering rate} = \frac{\text{Area of proximity region}}{\text{Area of coronoid region}} \times 100 \, (%)$$

We also investigated the resection region at the time of olecranon graft harvest and calculated the resection area by dividing the ulnohumeral articular facet area by the cutting plane. The resection rate was defined by the following equation:

$$\text{Resection rate} = \frac{\text{Resection area}}{\text{Ulnohumeral articular facet area}} \times 100 \, (%)$$

We also investigated the location of the proximity region center to clarify the characteristics of each osteochondral graft.
The proximity center distance was defined as the distance between the planes perpendicular to the cutting plane passing through the coronoid process tip and the proximity region center (Fig. 5).

Differences in the values between the 3 osteochondral grafts were analyzed by the Tukey-Kramer test. Significance was established at $P < .05$.

**Results**

The articular facet of the olecranon graft and the lateral radial head graft predominantly covered the lateral convex portion of the coronoid process, and the proximal radial head graft covered the medial concave portion. The convex portion was a better match for the articular facet of the olecranon graft than for the lateral radial head graft (Fig. 6, A). The covering rates for the olecranon, lateral radial head, and proximal radial head grafts were 89.2% ± 6.2%, 80.3% ± 11.2%, and 81.5% ± 11.0%, respectively (Figs. 6, B and 7, A; Table I). The covering rate was significantly higher in the olecranon graft than in the lateral and proximal radial head grafts ($P < .05$ and $P < .05$, respectively).

The proximity region center of the proximal radial head graft was more medial compared with that of the olecranon...
and lateral head grafts. The proximity center distances in the olecranon, lateral radial head, and proximal radial head grafts were 4.0 ± 1.4 mm, 4.2 ± 1.3 mm, and 5.4 ± 1.4 mm, respectively (Figs. 6, B and 7, B). The proximity center distances were significantly greater in the proximal radial head grafts than in the olecranon and lateral radial head grafts (both \( P < .05 \)).

The ulnohumeral articular facet area, resection area, and resection rate were 922 ± 147 mm\(^2\), 127 ± 31 mm\(^2\), and 13.8% ± 2.6%, respectively (Table I).

### Discussion

Coronoid process reconstruction with an osteochondral bone graft by use of the radial head and olecranon has been reported for persistent posterior elbow dislocation with comminuted fracture of the coronoid process. In this study, the coronoid articular facet was reconstructed with the olecranon tip articular facet, radioulnar articular facet of the radial head, or radiocapitellar articular surface of the radial head. However, 3D articular facet suitability between the articular shapes of the osteochondral autograft and coronoid process rarely receives much attention. Therefore, we attempted to evaluate the 3D articular facet suitability of 3 osteochondral grafts for coronoid process reconstruction.

Our results revealed that the covering rate was significantly higher with the olecranon graft than with the lateral and proximal radial head grafts, presumably because the olecranon and coronoid tips were convex in the coronal plane and the trochlear ridge of the proximal ulnar surface was almost semicircular in the sagittal plane, although the radial head was ellipsoidal laterally in the axial plane and proximally concave in the coronal plane.

The proximity center distances were significantly greater in the proximal radial head grafts than in the olecranon and lateral radial head grafts. The proximity region of the proximal radial head graft was significantly medial compared with that of the olecranon graft. Therefore, we assumed that the olecranon tip graft was suitable for a defect of the coronoid process including the tip and that the proximal radial head graft was suitable for a defect of the coronoid process including the anteromedial rim.
Some authors have described clinical outcomes of coronoid process reconstruction with osteochondral grafts. Moritomo et al\textsuperscript{10} used the ipsilateral olecranon tip as an osteochondral autograft to reconstruct the coronoid process in patients with persistent elbow dislocation and achieved painless and stable joints with a functional range of movement. However, clinical outcomes of reconstruction with a radial head graft are controversial. van Riet et al\textsuperscript{18} used a lateral articular facet of the radial head, with Mayo Elbow Performance Scores of 1 excellent, 2 good, 1 fair, and 2 poor, and they noted that the outcome was unpredictable. Ring et al\textsuperscript{16} treated 8 patients with unreconstructable coronoid fractures with the proximal articular facet of the radial head; 5 patients obtained satisfactory functional outcomes. However, 3 patients had only fair Mayo Elbow Performance Scores, and 5 had radiographic signs of arthrosis. These clinical outcomes may agree with our results if the differences in articular facet suitability were factored into the clinical outcome.

The olecranon graft is harvested from the ipsilateral olecranon tip without reconstruction of the olecranon tip. Therefore, the consequences of olecranon resection must be considered. The effect of partial olecranon removal has been described in clinical and biomechanical studies. A clinical study suggested that up to 80\% of the olecranon may be removed with little functional loss.\textsuperscript{8} An et al\textsuperscript{1} investigated varus-valgus instability in extension and 90° flexion after sequential olecranon resections in a cadaveric biomechanical study and reported that removal of ≤50\% of the olecranon does not usually cause instability. Bell et al\textsuperscript{2} investigated the effect of serial olecranon resections on elbow kinematics and stability. Elbow stability was progressively lost with sequential excision, with gross instability noted at resection of ≥87.5\% of the olecranon.

\textbf{Figure 6}  (A) 3D models of the original ulna (white), duplicated ulna (transparent light blue), and radius (transparent light blue) viewed from the anterior side are shown after the olecranon tip of the duplicated ulna model (top), lateral radial head (middle), and proximal radial head (bottom) were semiautomatically superimposed on the corresponding part of the coronoid process of the original ulna model. Note that the shapes of the olecranon and coronoid tips were convex and similar to each other. (B) Proximity region on the original ulna model viewed from the proximal side is shown. Note that the proximity region of the olecranon graft was more medial compared with that of the proximal radial head graft.
Abrupt changes in elbow kinematics occurred with ≥75.0% resection for active valgus stress, and 2 distinct changes in elbow kinematics occurred at 37.5% and 75.0% resection with active varus stress. In our study, for 50% loss of the coronoid process, only 13.8% ± 2.6% of the olecranon needed to be resected, suggesting that olecranon removal would not cause gross elbow instability.

There are some other clinical concerns that must be considered in choosing a graft. The radial head graft can often be harvested from the discarded fragment of a radial head fracture, followed by radial head arthroplasty16,18;
however, the radial head graft is not available in cases in which the radial head is severely damaged or has already been lost. In such a case, the use of an olecranon graft would be preferable. A proximal radial head graft would be preferred in cases in which the anterior rim has already been lost, and the radial head graft can be harvested from the discarded fragment because the proximity region of the proximal radial head graft was significantly medial compared with that of the olecranon graft. However, the potential of the proximal radial head graft to control for valgus stability is unknown if the anterior bundle of the ulnar collateral ligament is disrupted. The lateral radial head graft might be used to correct a defect of the coronoid process, including the tip, if the discarded radial head is used in cases of a terrible triad injury. However, compared with an olecranon graft, a radial head graft may not have the potential to control posterior stability because the covering rate was significantly lower with a radial head graft than with an olecranon graft.

The vascularity of the graft may also be a matter of concern. These grafts are free nonvascularized osteochondral grafts and have a risk of avascular necrosis, although avascular necrosis of olecranon and radial head grafts has not been described previously.10,16,18

This study had some limitations. First, we could not consider the important shape of the articular cartilage surface because this study was CT based. The variability of cartilage thickness of the elbow has been reported.12,15,17 In the future, a study looking at the articular facet configuration including the cartilage thickness may be needed. Second, we did not calculate the volume of each graft because it is technically difficult to determine the distal border of the graft accurately. Each graft may have a different advantage for fixation in terms of size and number of screws. Third, the small number of elbows limited the accuracy of the comparisons.

Our study evaluated 3D morphologic characterization of osteochondral autograft for coronoid process reconstruction. In terms of articular facet configuration, an olecranon graft was most suitable for a defect of the coronoid process including the tip, and a proximal radial head graft was most suitable for a defect of the coronoid process including the anteromedial rim. We believe our study findings will be helpful in selecting an osteochondral autograft for coronoid process reconstruction.

**Conclusion**

An olecranon graft was most suitable for defects of the coronoid process including the tip, and a proximal radial head graft was most suitable for defects of the coronoid process including the anteromedial rim. An olecranon graft for the reconstruction of up to 50% of the height of the coronoid process did not use enough of the ulnohumeral articular facet to cause concern for gross elbow instability.

**References**


