Scaphoid Osteochondral Graft for Reconstruction of the Distal Radius: A Novel Computational Method and Case Study

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Report of a case

A 25 year-old male sustained a complex, open radiocarpal fracture-dislocation with bone loss (Figure 1). The large defect in the lunate facet of the distal radius was reconstructed with the remaining distal pole of the scaphoid, allowing for motion-preserving proximal row carpectomy rather than total wrist fusion (Figure 2). At one year follow-up, our patient had no pain with wrist flexion 15° and extension 20°.

Figure 1: Preoperative radiographs of the left hand demonstrate a complex, open distal radius fracture-dislocation with loss of bone at the distal radius and proximal pole of the scaphoid.

Figure 2 (left) Post-operative radiographs demonstrate a lateral (A) and AP (B) view of the patient's left hand. The scaphoid osteochondral graft was secured with one screw and k-wire, and the wrist joint was stabilized with a trans-articular k-wire through the distal radius and capitate. Six weeks postoperatively the radiocapitate wire was removed, and boney healing may be seen on lateral (C) and AP images (D).

Objectives

Identification of novel osteochondral grafts has traditionally been limited to visual comparison of graft and host shape with or without 2 dimensional measurement of radius of curvature of the articular surface.

We sought to create software that could use CT scan images as input and digitally compare two three-dimensional surfaces to determine graft potential quantitatively.

Methods

The iterative closest point (ICP) algorithm iteratively determines the optimal position of a model surface to minimize the sum of squares of distances from all points on a target surface. Custom open-source software was created to optimally align two surfaces of differing shapes. The algorithm began with a "best guess" alignment. It then located the nearest-neighbor point on the larger surface for every point on the smaller surface. An optimization process was then performed during which the relative positions of the surfaces were varied in order to determine a global minimum value for the sum of squares of the distances between all nearest-neighbors. The mean residual distance (MRD) between nearest-neighbors and the standard deviation were then calculated. The proportion of points <0.5mm from their nearest-neighbor was also reported, and a color plot of the distances was rendered. A simplified example using a hemi-sphere and hemi-ellipse is shown in Figure 3.

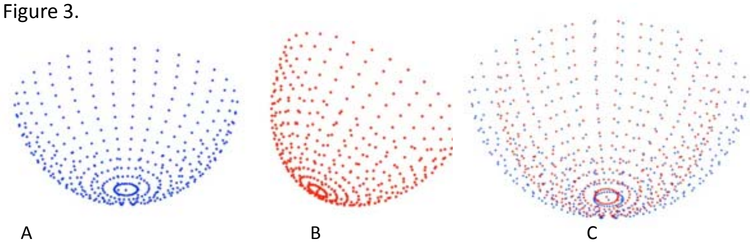
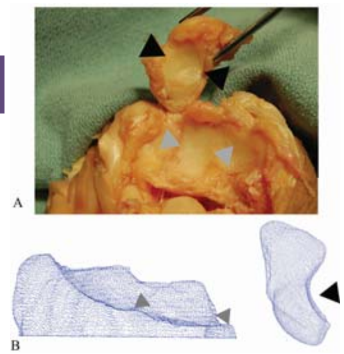


Figure 3: (A) a hemi-sphere and (B) a hemi-ellipse are translated in space to their optimal pose with the ellipse inside of the sphere (C).

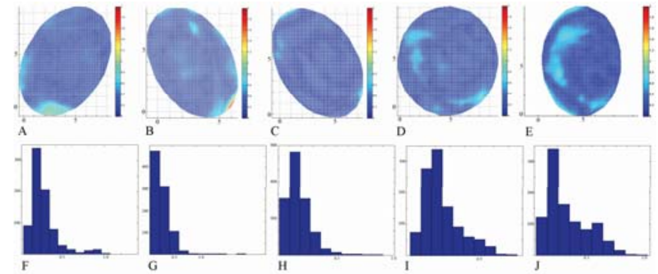


To evaluate the software as a means to identify new osteochondral grafts, we applied it retrospectively to evaluate the fit of the scaphoid to the lunate facet of the distal radius as seen in the case study presented. CT scans of five wrists were digitally rendered (Figure 4B). The capitate facet of the scaphoid was fit to the lunate fossa of the distal radius using the above described technique.

Figure 4: (A) Distal radius and scaphoid articular surfaces in a cadaveric specimen and digitally rendered (B). Grey arrows indicate the lunate facet; black arrows indicate the capitate facet of the scaphoid.

Results

The MRD for the five subjects was found to be 0.25mm, with 82.8-98.3% of the articular surfaces within 0.5mm of each other (Table 1, Figure 5).



	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
Mean Residual distance (mm)	0.2643	0.2784	0.1802	0.2440	0.2889
Standard Deviation	0.1651	0.2086	0.1111	0.1275	0.1787
% nearest neighbors <0.5mm apart	92.5	89.8	98.3	93.3	82.2

Figure 6 A-E: Contour plots representing the distances between nearest-neighbors when the two articular surfaces were optimally aligned for Specimens 1-5. The color scale shows distances from 0 to 2 mm. F-J: Distribution of nearest-neighbors distances for the plots shown above.

Conclusions

Advantages

- Quantitative method for describing "fit" of novel osteochondral grafts
- Ability to create rich, 3-dimensional representations versus traditional, 2-dimensional radius of curvature assessment

Limitations

- Algorithm allows joint surfaces to penetrate each other; this is acceptable for reconstructive procedures but cannot currently measure congruency of native joints

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