Three-dimensional morphometry of the proximal ulna: a comparison to currently used anatomically preshaped ulna plates

Paul Puchwein, MDa,*, Thomas Armin Schildhauer, MDa, Sylvia Schöffmann, MDa, Nima Heidari, MDb, Gunter Windisch, MDC, Wolfgang Pichler, MDa

aUniversitätsklinik für Unfallchirurgie, Medizinische Universität Graz, Graz, Austria
bRoyal London Hospital, London, UK
cInstitut für Anatomie, Medizinische Universität Graz, Graz, Austria

Background: Anatomically preshaped plates are increasingly used for stabilization of comminuted olecranon and Monteggia fractures. The purposes of this study were to investigate the morphology of the proximal ulna and to compare morphologic findings with geometry of 4 preshaped ulna plates.

Materials and methods: Forty human elbows (mean age, 68 years; range, 21-98 years) were measured by 2 independent observers using 64-slice computed tomography scans and 3-dimensional measuring software.

Results: Measurements showed a mean dorsal hook angle of 95.3° ± 9.0° (range, 74.7°-110.8°) with gender-specific differences (mean, 92.2° ± 8.1° in men and 98.3° ± 8.9° in women; P = .029); a mean distance from the tip of the olecranon to the proximal edge of the ulna of 24.7 ± 2.7 mm (range, 20-30.5 mm) with gender-specific differences (P = .00068); a mean varus angulation of 14.3° ± 3.6° (range, 5.8°-21.2°); and a mean anterior angulation (proximal ulna dorsal angulation) of 6.2° ± 2.7° (range, 1.0°-11.2°). The investigated plates offered a tolerable (+ standard deviation) hook angle in 25% to 68%, an appropriate varus angulation in 0% to 20%, and an adequate anterior angulation in 23% to 88%. The intraclass correlation coefficient was between 0.74 and 0.91.

Conclusion: The proximal ulna has a gender-specific and variable morphology. Some currently used anatomically preshaped proximal ulna plates differ significantly from these morphologic findings. In cases where reduction is not exactly possible, application of an “anatomically preshaped” plate may result in poor reduction. Especially in case of Monteggia fractures with instability of the radiocapitellar joint, surgeons could be misguided by plates that do not incorporate anterior angulation, resulting in subluxation of the radial head on the capitellum.


Keywords: Preshaped ulna plates; morphometry of proximal ulna; Monteggia fracture
In recent years, anatomically preshaped plates have become increasingly available and sold by industry. Using these preshaped plates in daily clinical practice has shown that, on many occasions, these plates do not fit the proximal ulna as promised by the term “anatomically preshaped plate.” The reason for this discrepancy may be variable anatomy of the proximal ulna. A review of the literature showed a paucity of published articles about the ulna’s morphologic variations—especially with regard to the hook angle, varus angulation, and anterior deviation of the proximal ulna. The term “hook angle” describes the angle between the proximal plane of the ulna from the tip to the triceps insertion area and the dorsal plane distal from the triceps insertion area. Anterior angulation of the proximal ulna is diametrically described as proximal ulna dorsal angulation (PUDA) by some authors, meaning the same dorsal “apex” of the proximal ulna.

The purposes of this human morphologic study were (1) to investigate the 3-dimensional (3D) morphometry of the proximal ulna (dorsal hook angle and anterior and varus angulation) by use of high-resolution computed tomography (CT) scans and 3D reconstruction software and (2) to compare the anatomic/morphologic findings with the geometry of 4 clinically used preshaped proximal ulna plates.

Materials and methods

Type of study

In this anatomic study, we investigated the morphometry of human ulnae by measuring 6 different distances and 3 different angles and comparing the study results with 4 anatomically preshaped olecranon plates.

Population selection

Forty human elbows were included in this study. We used 30 cadaveric elbows, preserved according to the embalming method of Thiel. To increase the number of subjects and include younger patients, we included 10 adequate CT scans of patients treated in our hospital during the last few years with radial head fractures. Elbows with severe arthrosis, radiologic evidence of trauma to the ulna, or other observable pathologic changes were excluded from this study.

Radiologic method

The osseous anatomy of the elbows was digitized in the supine position with a 64-slice Siemens SOMATOM Sensation CT system (0.6-mm contiguous axial slices; Siemens Medical Solutions, Malvern, PA, USA). DICOM (Digital Imaging and Communications in Medicine) raw data sets were reconstructed by use of the 3D software program MIMICS (Materialise, Leuven, Belgium) (Figs. 1 and 2).

Morphologic measurements

For all measurements after 3D reconstruction, the first reference point for measurements of the olecranon morphology was set at the middle of the proximal surface of the semilunar notch (“tip” of the olecranon). By setting additional measurement points at the middle of the proximal plane of the olecranon (point 1 at 7 mm and point 2 at 17 mm distal to the tip of the olecranon) and 2 further points along the shaft (point 3 at 5 mm and point 4 at 20 mm distal to the “edge” point), the angle of the hook was calculated (\( \alpha \) in Fig. 1). The mediolateral width of the proximal ulna was measured at 3 levels: level 1, triceps insertion; level 2, proximal ulnar shaft (20 mm distal to the edge point), and level 3, midshaft of the ulna (80 mm below the edge point). The angulation of the proximal and middle ulnae in the frontal and sagittal planes (varus and anterior deviation) was measured in the 3D reconstructed mode. The varus angulation was measured between the axis of the olecranon (line defined by points 3 and 4) and the ulna midshaft axis as presented in Figure 2. The anterior angulation (PUDA) was given similarly between these 2 lines in the lateral view (Fig. 1). The point of rotation for the varus and anterior angulation was defined, and the distances between these 2 points and the edge point were measured.

The accuracy of this technique was limited by the resolution of the CT scans with ±0.5 mm for all measured dimensions.

Plates used for comparison

Four locally distributed and commonly used preshaped olecranon/proximal ulna plates were analyzed by use of data provided by the manufacturers or measured with a goniometer 3 times (hook angle for plate C - longest plate, anterior angulation for plate A - longest plate) (Table I):

Plate A was the LCP Olecranon Plate (6 different lengths from 86-216 mm, left/right plates; Synthes, Solothurn, Switzerland).
Plate B was the PERILOC Olecranon Locking Plate (5 lengths from 56-157 mm, left/right plates; Smith & Nephew, London, England).
Plate C was the Olecranon Plate (4 different lengths, no chirality; ITS GmbH, Lassnitzbühre, Austria).
Plate D was the Acumed Olecranon Plate (5 lengths for standard plate and 2 lengths for extended plate, left/right plates; Acumed, Hillsboro, OR, USA).
To find the most suitable plate among these 4 products, we decided to define the mean value ± standard deviation of the study results as the “tolerable” range for each plate.

Statistical methods

The results were exported into Excel sheets (Microsoft Excel 2003; Microsoft, Redmond, WA, USA) for analysis. With the Excel plug-in XLStatistics (Rodney Carr, Allansford, Victoria, Australia), the 2-sample t test was used for calculating gender- and side-dependent differences. By use of the Pearson correlation coefficient, we searched for age-dependent morphologic correlations. \( P \leq 0.05 \) was considered statistically significant.

By use of comparable measurements from 2 studies, it was possible to calculate the effect sizes and needed sample sizes for PUDA and anterior angulation point.\(^{11,14}\)

We calculated an a posteriori sample size following Jones et al.\(^6\) to validate the results concerning gender dependency for hook angle and the distance “tip to edge point.”

All elbows were evaluated and measured by 2 independent observers. PASW Statistics 18 for Windows (SPSS, Chicago, Illinois, USA) was used to calculate intraclass correlation coefficients (ICC 3,1). On the basis of good ICCs (as described in the “Results” section), the mean value of both observers was taken for all measurement results.

Results

Population

The mean age was 67.7 years (SD, 19.7 years; range, 21-98 years). Overall, there were 17 left and 23 right elbows from 40 different persons to minimize the influence of symmetry. The ratio between male and female subjects was 1:1.

Morphologic measurements

The mean olecranon dorsal hook angle was 95.3° (SD, 9.0°). We found a significant gender-dependent difference in this angle (\( P = 0.029 \); mean in men, 92.2° [SD, 8.1°]; mean in women, 98.3° [SD, 8.9°]) (Table II). The mean length between the tip of the olecranon and the edge point was 24.7 mm (SD, 2.7 mm) (mean in men, 26.1 mm [SD, 2.3 mm]; mean in women, mean, 23.4 mm [SD, 2.4 mm]),...
and we observed a highly significant gender-specific correlation \( (P = .00068) \). A mean varus angulation of 14.3° (SD, 3.6°) and a mean anterior angulation (PUDA) of 6.2° (SD, 2.7°) were found. The mean varus angulation point was measured at 75.0 mm (SD, 7.9 mm), and the mean anterior angulation point was at 44.4 mm (SD, 7.4 mm). The mediolateral width of the ulna was measured at 3 different levels, with a mean of 22.9 mm (SD, 2.6 mm) at the tip of the olecranon at level 1, a mean of 11.7 mm (SD, 2.3 mm) at level 2, and a mean of 15.2 mm (SD, 1.9 mm) at level 3 (Table III). All measurement results including mean values, standard deviations, and ranges are summarized in Table II. No significant age-dependent correlations of the measurements were found.

**Plate dimensions**

Referring to the manufacturer’s data, plate A features a hook angle of 110°, a varus angulation of 8.4° for all dimensions, and no anterior angulation in our direct measurement. Plate B features a flexion of 81° (with a hook angle \( \alpha \) of 99°), a varus angulation of 7°, and a mean anterior angulation of 8° (varying a little in the distal part of the plate and depending on plate length). Therefore, both plates must be provided in right and left versions. The manufacturer’s geometrical data for the ITS plate were unavailable. The direct measurement of the longest implant showed a hook angle of approximately 100°, no anterior angulation, and no varus angulation. Plate D is provided in a standard version and an extended version. The standard version with prongs features a hook angle of 124° and is directly placed over the triceps tendon, whereas the proximal extended version features a hook angle of 100°. A varus angulation of 8° and an anterior angulation of 6° for the plates were specified by the manufacturer. All those data are summarized in Table I in comparison to the mean morphologic measurements of this study.

By use of the mean value ± standard deviation as “tolerable range,” plate A fits in 10 of 40 cases (25%) concerning hook angle, in 8 of 40 cases (20%) concerning varus angulation, and in 9 of 40 cases (23%) concerning anterior angulation. For plate B, the hook angle fits in 27 of 40 cases (68%), varus angulation in 6 of 40 cases (15%), and anterior angulation in 31 of 40 cases (78%). Plate C features a dense hook angle in 27 of 40 cases (68%), an adequate varus angulation in 0 of 40 cases (0%), and an adequate anterior angulation in 9 of 40 cases (23%). The hook angle of plate D was appropriate in 27 of 40 cases (68%), varus angulation was acceptable in 0 of 40 cases (0%), and anterior angulation was acceptable in 35 of 40 cases (88%) (Table I).

**Verification of results' validity**

The ICC for the hook angle was 0.759, with a 95% confidence interval (CI) from 0.589 to 0.865. The ICCs were 0.810 (95% CI, 0.659-0.897) for the tip-to-edge point distance, 0.908 (95% CI, 0.832-0.95) for varus angulation, 0.740 (95% CI, 0.560-0.853) for varus angulation point, 0.806 (95% CI, 0.663-0.892) for anterior angulation, and 0.864 (95% CI, 0.757-0.926) for anterior angulation point. For the width of the ulna, we calculated an ICC of 0.762 (95% CI, 0.594-0.867) at level 1, 0.883 (95% CI, 0.791-0.936) at level 2, and 0.824 (95% CI, 0.693-0.903) at level 3.

The effect sizes for gender-dependent differences in the literature concerning PUDA were 0.286 to 0.815, and they were 1.01 to 1.07 for the anterior angulation point.11 In a further study we found effect sizes between 0.099 and 0.215 for PUDA and anterior angulation point.14

When we calculated the effect sizes of this study a posteriori, the result for the hook angle was 0.678 (sample size \([n] = 40\), power level \(b = 0.8\)) and the result for the distance from the tip of the olecranon to the edge point was 1.0 (sample size \([n] = 17\), level \(b = 0.8\)).

**Discussion**

Malreduction and malunion of the proximal ulna can affect 3 joints: the radiocapitellar joint (as in Monteggia fractures), the ulnohumeral joint (closing or opening the joint surface can lead to arthritis), and the proximal radioulnar joint with its effect on pronation and supination.

In recent years the use of anatomically preshaped plates has become increasingly popular. Because most preshaped plates provide fixed angled screws, perfect fit to the bone may not be necessary for stable fracture fixation. However, the proximal ulna has a thin soft-tissue cover, and metal-work left proud may become prominent and be uncomfortable for the patient. The purpose of this anatomic study was to determine how well commercially available anatomically preshaped plates match true proximal ulnar anatomy in a selected cadaveric population. To obtain the
most accurate measurements, we used 64-slice CT scans and 3D measuring software.

A review of the literature showed only a few anatomic studies dealing with the anatomy of the proximal ulna and none dealing with the hook angle or focusing on the fit of anatomically preshaped plates. Grechenig et al\textsuperscript{5} examined 54 cadaveric specimens and observed a varus angulation in the proximal third of 17.5° (range, 11°-23°) and a mean anterior angulation of 4.5° (range, 1°-14°). They recommend a preoperative radiograph of the contralateral elbow. After reduction and stabilization, the postoperative radiographs should be compared with those of the contralateral side.\textsuperscript{5}

Windisch et al\textsuperscript{15} examined 74 cadaveric specimens, focusing on the course of the posterior border of the ulna, the point of varus angulation, and the width of the shaft. The mean point of varus angulation was 85.4 mm, and a mean varus angulation of 17.7° was found. The varus angulation differs by less than 3° in comparison with the results of our study, whereas the mean point of varus angulation was greater compared with our study because of different measuring techniques (Windisch et al did not measure from the edge point but from the tip of the olecranon).

In further study Windisch et al\textsuperscript{14} focused on intramedullary nailing of ulna fractures. They examined the relation between the palpable posterior border of the ulna and the curvature of the medullary cavity in 80 cadaveric bones, finding that the palpable posterior border does not reliably give an indication of the curvature of the medullary cavity.

The (minor) differences in the resulting angles between these studies and the results of our study could be explained by different measurement techniques: Grechenig et al\textsuperscript{5} and Windisch et al\textsuperscript{14,15} used simple optical and photographic techniques.

Wang et al.\textsuperscript{13} dissected 39 cadaveric elbows to determine ulnar length, diameter of the medullary canal, olecranon bare area, and varus angulation point. The latter was measured at 7.6 cm from the edge point, nearly matching the study results (mean, 75 mm).

Measuring 100 elbows in 50 patients, Rouleau et al\textsuperscript{11} found a reliable method of determining the anterior angulation (PUDA) on conventional radiographs by using the contralateral elbow. They measured a mean angle of 5.7° (range, 0°-14°) and a tip-to-apex distance of 47 mm (correlating to the anterior angulation point of 44.4 mm in this study), whereas the “tip” matches with the edge point in this study.

The purpose of this anatomic study was to discuss the results focusing on the geometry of currently available anatomically preshaped plates. Given the variable anatomy of the proximal ulna, the use of a rigid preshaped plate produced in only 1 specific shape should be reconsidered. The mean hook angle in this anatomic study was 95.3°. Particular attention must be paid to the broad range of the hook angle (74.7°-110.8°). This clearly shows that the use of an anatomically preshaped plate without bending of the hook angle may not be advisable in all cases. Some plates with shorter olecranon “arms”—such as the standard version of plate D—are intentionally designed with a nonanatomic hook angle to lay on the triceps tendon. However, in complex fractures with the need for an extended olecranon “arm,” a discrepancy between the hook angle of the plate and that of the bone may result in 2 different problems: (1) If the hook angle of the plate is less than that of the patient, the fracture could be forced in the wrong position and anatomic reduction of the fracture is thus unlikely, causing a malreduction and subsequent malunion, which may lead to a loss of joint congruity and a poor functional outcome. (2) If the plate does not conform well to the proximal ulna, it may become prominent and easily palpable at the subcutaneous border of the ulna, which may be a source of discomfort, dissatisfaction, and risk of wound healing problems for the patient. Therefore, it may be an advantage if the preshaped plate can still be bent into an optimal overall shape. When the 4 chosen plates are compared with regard to the hook angle, plates B, C, and D are suitable for 68% of the study elbows.

In addition to the normal range of hook angles, the proximal ulna also shows a varus angulation (mean, 14.3°; range, 5.8°-21.2°) and an anterior angulation, or PUDA (mean, 6.2°; range, 1.0°-11.2°). Our study shows a distinct gender difference in proximal ulnar anatomy. In fact, gender

### Table III Measurement results for both genders

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Mean</th>
<th>Range</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hook angle</td>
<td>95.3°</td>
<td>74.66°-110.77°</td>
<td>9.0°</td>
</tr>
<tr>
<td>Tip of olecranon to edge point</td>
<td>24.7 mm</td>
<td>20.0-30.5 mm</td>
<td>2.7 mm</td>
</tr>
<tr>
<td>Varus angulation</td>
<td>14.3°</td>
<td>5.8°-21.2°</td>
<td>3.6°</td>
</tr>
<tr>
<td>Varus angulation point*</td>
<td>75.0 mm</td>
<td>56.0-86.3 mm</td>
<td>7.9 mm</td>
</tr>
<tr>
<td>Anterior angulation (PUDA)</td>
<td>6.2°</td>
<td>1.0°-11.2°</td>
<td>2.7°</td>
</tr>
<tr>
<td>Anterior angulation point*</td>
<td>44.4 mm</td>
<td>31.9-69.3 mm</td>
<td>7.4 mm</td>
</tr>
<tr>
<td>Width of ulna</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At level of triceps insertion</td>
<td>22.9 mm</td>
<td>17.1-27.9 mm</td>
<td>2.6 mm</td>
</tr>
<tr>
<td>2 cm below edge point</td>
<td>11.7 mm</td>
<td>7.4-16.4 mm</td>
<td>2.3 mm</td>
</tr>
<tr>
<td>8 cm below edge point</td>
<td>15.2 mm</td>
<td>11.3-18.4 mm</td>
<td>1.9 mm</td>
</tr>
</tbody>
</table>

* Measured from edge point.
differences of the proximal ulna have already been described in the literature: Cowal and Pastor\textsuperscript{3} examined the notch length, the width of the olecranon process, and the height of the coronoid process in 223 skeletons, finding significant differences between the male and female ulnae.

Summarizing all provided features of the 4 plates, we found that plate D was the most suitable plate for our elbows (Table I).

This heterogeneity in proximal ulnar anatomy means that producing an anatomically preshaped plate providing the perfect fit in all cases is impossible. In cases where the hook angle of the plate is less than that of the patient’s malreduction, subsequent joint incongruity may be an issue, whereas a plate hook angle that exceeds that of the patient may leave prominent metal work. Overall, we identified that providing plates with a variety of hook angles as well as plates with a less rigid design better able to be contoured may extend the surgeon’s choice of implant and allow for reconstruction of the fracture anatomically.

Our study had some weaknesses. Unfortunately, there were no data provided about point of varus and anterior angulation of those plates offering these features. An exact measurement of those points was impossible because the plates are bent smoothly to those angles and are not angulated at a well-defined point. Further detailed information about plate designs (3D computer-aided design models of plates to match them with our CT scans) could not be obtained from the manufacturers (industrial secrets). We found no data about the hook angle and the tip-to-apex distance in the literature; therefore, an a priori power study was not possible for these results.

**Conclusion**

Especially in case of a Monteggia fracture with instability of the radiocapitellar joint, the surgeon could be misguided by plates that do not incorporate the apex of the anterior angulation (or PUDA) point, resulting in subluxation of the radial head on the capitellum. In case of a complex fracture of the ulna, we recommend measurement of the hook angle and the anterior angulation (PUDA) on a radiograph of the contralateral elbow. In many cases, recontouring of an “anatomically preshaped plate” is still necessary.

**Acknowledgments**

We thank our statistician, Gerold Schwantzer, for his effort and support.

**Disclaimer**

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

**References**