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Research Article

Understanding Proximal Ulna Anatomy on Fluoroscopic Images

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Abstract

Purpose: The three-dimensional anatomy of the proximal ulna can be difficult to interpret with standard intraoperative fluoroscopy. Without appropriate visualization, surgeons risk placing implants in suboptimal locations during fracture fixation of the proximal ulna. The purpose of this study was to delineate the borders of proximal ulnar anatomy, specifically, the trochlear ridge and the medial and lateral facets, and to provide measurements to assist surgeons with navigation of its complex anatomy.

Methods: We analyzed ten fresh-frozen cadaveric elbows: five female and five male specimens, with diverse ages and heights. Utilizing novel reference points, the center of the trochlea and the intersection of the ulnar axis and a perpendicular plumb line from the coronoid tip, we recorded measurements to adjacent anatomical landmarks.

Results: The distances from the center of the trochlea to the trochlear ridge, the medial facet, and lateral facet from the center of the trochlea as measured off of a custom reference line were 10.2 mm (95% confidence intervals 9.7 to 10.6 mm), 13.6 mm (95% CI; 12.4 to 14.8 mm), and 11.2 mm (95% CI; 10.9 to 11.5 mm), respectively. When evaluating our referencing technique, we found inter-observer and intra-observer reliabilities to be dependable at 0.85 to 0.98 for all measurements, respectively.

Conclusions: This cadaveric study provides simple radiographic parameters that should be considered when placing implants about the trochlear notch of the proximal ulna to avoid aberrant hardware placement.

Keywords: Proximal Ulna Anatomy; Intraoperative Fluoroscopy; Elbow Joint; Elbow Joint Surgery; Ulna Surgery; Basic Science Study

Introduction

The proximal ulna has a complex anatomy that has been extensively studied with cadaveric dissections, advanced imaging, and computer mapping software for the purposes of guiding implant placement [1,3-8,10,14,19,23,24]. While this information certainly has been useful, intra-operatively, surgeons most often rely on fluoroscopy to assess for proper implant placement and to navigate around the articular surface. Even with the most sophisticated fluoroscopic technology, important portions of this anatomy are oftentimes difficult to visualize. Techniques to identify these more obscure anatomic landmarks under fluoroscopy are still lacking in the literature. Without appropriate visualization, surgeons risk inadvertently accepting malreductions or placing implants in suboptimal locations, even within the joint. While the lateral facet of the trochlear notch is readily identifiable on a lateral view of the elbow, the medial facet and trochlear ridge are not as evident. The purpose of this study was to provide objective measurements to assist surgeons with intra-operative identification of these landmarks during fracture fixation.

Materials and Methods

This study was a cadaveric anatomic review of proximal ulna fluoroscopic landmarks and thus received exemption from our Institutional Review Board review. Ten fresh frozen cadaveric upper extremities amputated at the mid-shaft humerus were utilized in this study. The group consisted of five female and five male specimens with a mean age of 62 years (range of 40 to 85 years). Selected female cadaveric specimens ranged between 152.4 cm and 157.5 cm in height and males between 182.9 cm and 187.7 cm to allow for analysis of the normal anatomic variation a surgeon would expect to encounter in practice [15]. Radiographic markers were first placed in each specimen along the trochlear ridge and the medial facet to allow for easy identification under fluoroscopy. A custom radiographic scale (Figure 1) was placed next to the specimen to ensure both accuracy and consistency of measurements and to account for any variability in image magnifications. True lateral static fluoroscopic images were then obtained of each specimen using a standard large C-arm [2]. Finally, images were printed and measurements were recorded for each landmark of interest utilizing a line drawn between two novel reference points.

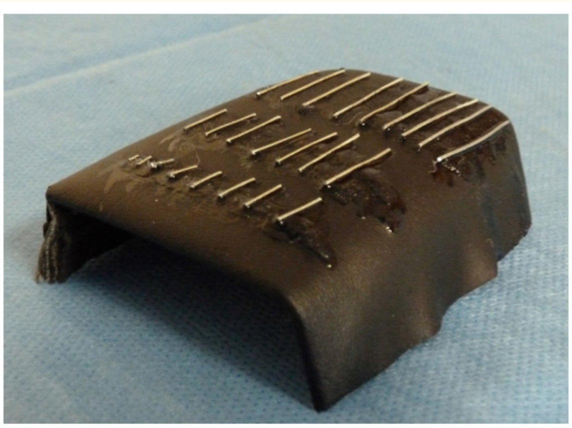

Figure 1: Custom radiographic scale.

Placement of radiographic markers

The articular surfaces of each cadaveric specimen were exposed with a standardized dissection protocol. The central trochlear ridge as well as the deepest portion of the medial fossa were subsequently lined with a 22-gauge stainless steel wire and secured in place with tissue adhesive (VetBond, 3M, St. Paul, MN) (Figure 2). The lateral facet was not marked, as it is easily visible. To ascertain anatomic joint congruency in each of the specimens, the soft tissue structures that were violated during the initial dissection were methodically repaired after the articular surfaces were prepared. This included repair of both the anterior and posterior capsular tissues, the origin of the medial collateral ligament to the distal humerus, and the flexor pronator mass origin on the humeral epicondyle.

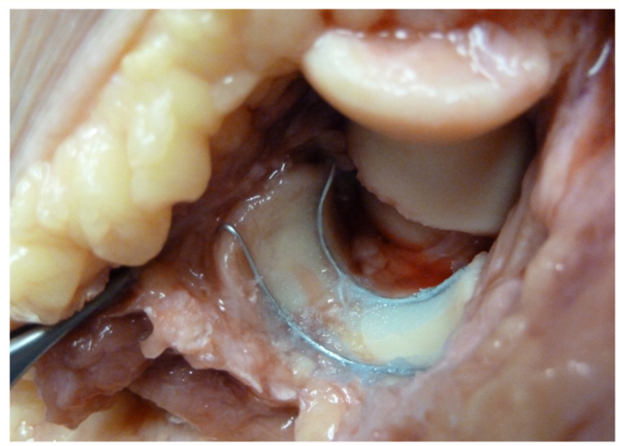

Figure 2: Cadaveric elbow joint. Pictured is the implanted intra-articular steel wire radiographic marker.

Measurement protocols

The prepared specimens were then imaged with fluoroscopy. Included in each of the fluoroscopic images was a customized scale to account for variability in magnification. All radiographic images were then printed. Two reference points were then drawn on each printed image and resultant. The first reference point was defined by the center of the trochlea. The second reference point was defined by the intersection of the ulnar axis and a perpendicular plumb line from the coronoid tip. The second reference point was chosen to represent the portion of the trochlear notch most likely to encounter an implant. Distances to each landmark being studied were determined off of a line connecting these two reference points as shown in figure 3. Two blinded observers independently determined these reference points and measured the distance from the center of the trochlea to the trochlear ridge, medial facet, and the lateral facet.

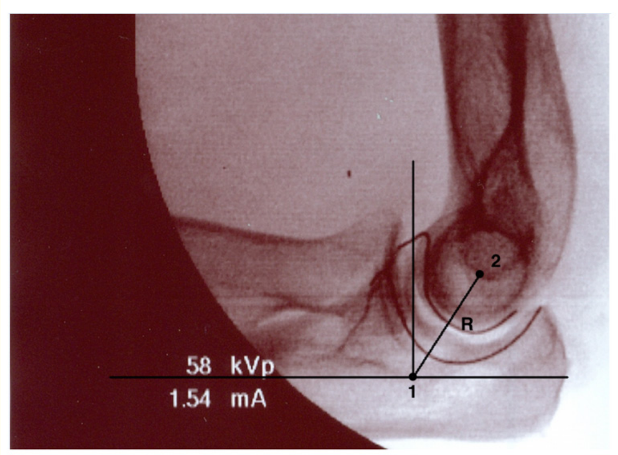

Figure 3: Lateral fluoroscopic image of the elbow. Demonstrated is the reference line (R) as defined by the following two points: 1) Point of intersection of the ulnar axis and a plumb line drawn down from the tip of coronoid 2) Center of the trochlea.

Statistical analysis

Ninety five percent confidence intervals were calculated for the three measurements in the small and large sample groups. The intraobserver and interobserver reliability were calculated for each measure with the Pearson correlation coefficient, Chronbach's alpha, and Ebel's reliability coefficients [21].

Results

In our study, the mean distances to the trochlear ridge, the medial facet, and lateral facet from the center of the trochlea were 10.2 mm (95% CI; 9.7 to 10.6 mm), 13.6 mm (95% CI; 12.4 to 14.8 mm), and 11.2 mm (95% CI; 10.9 to 11.5 mm) respectively. The male sub-group had average distances of 11.9 mm (95% CI; 11.3 to 12.4 mm), 16.6 mm (95% CI; 15.8 to 17.4 mm), and 14mm (95% CI; 13.3 to 14.7 mm), respectively. The female sub-group had average distances to the trochlear ridge, medial facet, and lateral facet from the center of the trochlea of 10.2 mm (95% CI; 9.72 to 10.63), 13.6 mm (95% CI; 12.43 to 14.77), and 11.2 mm (95% CI; 10.92 to 11.53) respectively. figure 4 summarizes the average measurements for each area of interest. Inter-observer and intra-observer reliabilities were good to excellent with values 0.85 to 0.98 for all endpoints as measured with the Pearson correlation coefficient, Chronbach's alpha, and Ebel's reliability coefficient (Table 1).

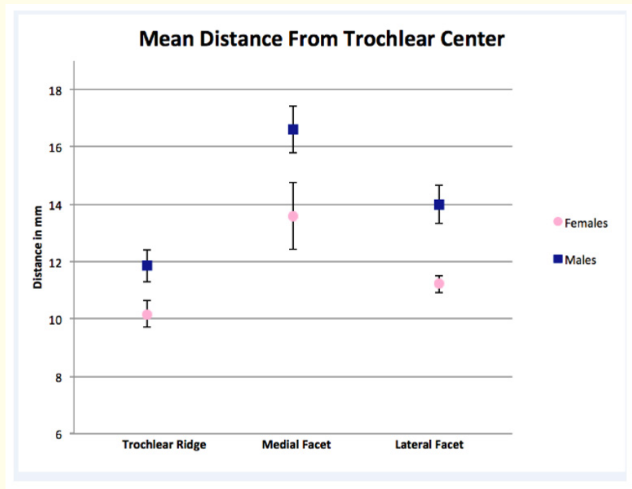

Figure 4: Box-and-Whisker Plot. Illustrated are the mean distances from the center of the trochlea to the trochlear ridge, medial facet, and lateral facet with 95% confidence intervals.

Calculated Intra-observer and Inter-observer Reliabilities				
		Ebel's Reliability	Pearson's	Cronbach alpha
Observer 1	Line A	0.85	0.91	0.95
	Line B	0.91	0.94	0.95
	Line C	0.96	0.96	0.98
Observer 2	Line A	0.95	0.9	0.96
	Line B	0.97	0.96	0.98
	Line C	0.96	0.95	0.98
Inter-observer	Line A	0.94	0.86	0.92
	Line B	0.96	0.94	0.96
	Line C	0.98	0.94	0.97

Table 1: Intra-observer and inter-observer reliabilities.

Discussion

Like many other diarthrodial joints, radiographic evaluation of the elbow is difficult [11,12,16,17]. Even with intra-operative fluoroscopy, poor visualization of the complex anatomy of the proximal ulna may result in sub-optimal fracture reduction or inadvertent violation of the articular surface during hardware placement (Figure 5). Both of these complications have been associated with diminished post-operative functional outcomes. [18,20] Wadia., *et al*. suggested utilizing measurements of width to length ratios of the olecranon and the trochlea to assess for adequate fracture reduction [22]. In their cadaveric study, Ozway., *et al*. suggested utilizing a fixed set of measurement parameters to avoid intra-articular penetration of K-wires during the application of a modified tension band in the setting of olecranon fractures [18]. While various indirect methods of delineating radiographic elbow anatomy have been described in the literature, to the best of our knowledge, we are the first to describe a reproducible technique that allows for more direct identification of key landmarks of the articular surface using standard intra-operative fluoroscopy [13,18,22].

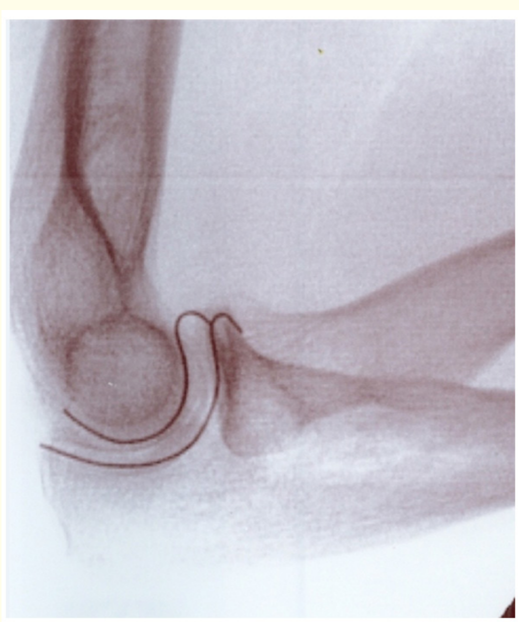

Figure 5: Lateral fluoroscopic image of the elbow. Demonstrated is the difficulty of visualizing the proximal ulna in many cases due to overexposure of the posterior cortex.

When navigating the proximal ulna during fracture fixation, reliable and easily identifiable landmarks are lacking. Duggal., *et al.* suggested using the flat spot at the posterior aspect of the olecranon as a reference for axial alignment while performing a total elbow arthroplasty [6]. It is our opinion that although *in vivo* visualization of the flat spot may be helpful in certain operative procedures, it is unclear how helpful this landmark may actually be for most fracture patterns. The center of the trochlea was chosen as our first reference point in this study because of its ease of reproducibility on a lateral radiograph. This landmark, while not identical to, closely corresponds to the flexion-extension axis described for use when applying an external fixator or performing a total elbow arthroplasty. We also introduce a novel secondary reference point to allow for the creation of a line of reference, from which measurements to the trochlear ridge, medial facet, and lateral facet can easily be made. Our inter- and intra-observer reliabilities demonstrated that this technique was easily reproducible for the purposes of measuring distances.

We have found that many of the cadaveric studies of ulnar anatomy in the literature demonstrate significant biases in regard to specimen selection [1,5,23]. We believe that this limits the applicability of study findings to the general population. While our sample size was small, our specimens were specifically chosen to represent the normal spectrum of anatomy in regard to anthropometric measurements. Specifically, specimens were selected to represent the extremes of height, thereby better encompassing the full spectrum of what an orthopedic surgeon might expect to encounter in the clinical setting. We recognize, however, that the clinical relevance of these details may not be significant, as even differences in measurements between the lower and higher extremes of the normal anatomy may amount to less than one millimeter, a difference surgeons may not be able to appreciate with current fluoroscopic technologies.

Based on our data, the medial facet measurements appeared to have the most variability. While this may have resulted from slight deviations in the placement of our radiographic markers i.e., experimental technique, the medial facet has been shown to have notable anatomic variation that may have accounted for the wider spectrum of measurements amongst our specimens [23]. This variability is important to note, especially during placement of a screw from posterior to the medial facet, as visualization of the medial facet on radiograph is already difficult. This is further complicated by the known limitations of intra-operative fluoroscopy [9,18]. The lateral facet, on the other hand, is well visualized as a discrete radiographic line intra-operatively. Thus, we recommend that any implants placed in the vicinity of the medial facet should remain approximately 2-3 mm farther from the apparent joint, along our line of reference, than the more easily visualized lateral facet to reduce the risk of unrecognized intra-articular penetration.

There are additional limitations to our study and the applicability of our findings. We are subject to the intrinsic limitations of a cadaveric study. Additionally, we acknowledge that intra-operative measurements are not necessarily practical nor do all fluoroscopic machines offer the option of calculating specific measurements.

Conclusion

We believe that our study gives surgeons a simple intra-operative tool to gauge the likelihood that an implant has been placed optimally within the bone without violating the articular surface.

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