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An assessment of proximal ulna dorsal angulation using digital radiographic images

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Abstract
Background: The architecture of adult ulna is unique among long bones that have been described in the literature. But the best of our knowledge, the dorsal angulation of proximal ulna has not been described in detail. While using newer straight precontoured ulnar plates, the recognition of PUDA is important anatomic landmark for surgeons treating proximal ulna fractures, nonunions, malunions or osteotomies. The importance of this study was to characterize the proximal ulna dorsal angulation (PUDA) in patients with bilateral elbow radiographs.
Materials & Methods: We examined bilateral elbow radiographs in 60 patients (30 male, 30 female), anteroposterior (AP) and lateral radiographs obtained. Measurements were recorded on each radiograph to identify the PUDA, later olecranon tip-to-apex distance of the PUDA was also measured.
Results: The statistical analysis of measurements of PUDA had shown no significant differences between right and left elbow. PUDA was found in 92% of radiographs. The mean value of the tip-to-apex distance between men and women was significantly greater in men.
Conclusion: Determination of the PUDA may be helpful in anatomic plating of the ulna for fractures, nonunions or malunions. Side to side correlation of PUDA measurements are reliable for recommendation to medical manufacturers for modelling ulna plates and components of artificial elbow joints.

Keywords: Angulation, proximal, ulna, radiograph, plates

1. Introduction
The severe injuries of proximal forearm often complicated with ulna fracture at its proximal end. The treatment of these fractures is very demanding; the anatomically preshaped ulna plates are commonly used in correction of the proximal ulna fractures. These plates are manufactured by medical manufacturers purported to efficiently fit with the structural anatomy of the proximal ulna, but based on practitioner's experience, in many cases the plates do not fit anatomically [1].
The anatomy of adult ulna has a unique bony architecture has been described in the literature. The morphometry of ulna has been previously described in several cadaveric studies with general consensus on the mean varus angulation of the proximal ulna and the mean distance from tip of olecranon process to the ulnar proximal angulation point [2]. Duggal *et al*. [3], found the 'flat spot' of the proximal ulna and suggested that this landmark is useful for component orientation during elbow arthroplasty. Failure of proper correction of proximal ulna fractures or olecranon osteotomy can lead to early arthritis, joint subluxation and loss of function.
Studies have reported morphometric analysis of the ulna with detailed anatomic features that are crucial for orthopaedic surgeons when treating fractures, nonunions, malunions, or during total elbow arthroplasty. Bone density initially adapts to external loads during growth phases while the trabecular architecture is acquired later during development [4]. The common knowledge of structural anatomy of ulna has curved posterior border. To simplify the measurements, two straight lines are using instead of one continuous curved line in recent advance studies. A cadaveric study of bilateral elbows has reported the ulnar length, the bare are of sigmoid notch, lateral varus angulation and ulnar cortical dimensions [5].
The important landmarks of the proximal ulna were described by several authors; most of them were studied in cadavers and dry bones. Therefore, their reproducibility and applicability in the real surgical set up are debatable. An anatomic study analysed dorsal apex curve (DAC) in eight pairs of normal cadaveric ulnae using the three dimensional serial CT images [6].

They identified dorsal angulation apexes were located at dorsal, varus, edge point. The feasibility of having CT images before proceeding for the surgery for treatment of proximal ulna fractures is questionable. Hence, the present study was designed to describe apexes and dorsal angulation of proximal ulna by using digital radiographic images of Indian population. The purpose of the study was to identify the location, magnitude of a proximal ulna dorsal angulation (PUDA) and distribution based on gender and age in Indian population.
The details of the current study on proximal ulna anatomy with determination of PUDA may be useful for surgical intervention involving plating of the proximal ulna, especially for selection precontoured proximal ulna plates.

2. Materials and Methods
The current research study was scrutinized and approved by the Institutional Ethical committee.

2.1 Sample
A standardized lateral view bilateral elbow radiographs of 60 consecutive patients (30 women, 30 men) were obtained for the study. Patients aged between 18 to 70 years were included in the study, and their mean age was 45 years. The quality of lateral view accepted with the identification of the 3 concentric arcs of the trochlear sulcus, capitullum, and the medial trochlea. None of the radiographs had the presence of arthritic lesions, signs of instability and deformity or any other lesion affecting the anatomy of the elbow.

2.2 Radiographic methods
All radiographs were obtained from radiology database from our institution. The images were enlarged by using imaging software. The 'flat spot' was identified on the dorsal part of the proximal ulna. The PUDA was determined by measuring the intersection angle tangent lines place on the 'flat spot' of the olecranon and the dorsal ridge of the ulnar shaft. The apex of the PUDA was identified by measuring the distance from the tip of the olecranon to the point of intersection of the PUDA tangent lines. All radiographs were examined by specialised orthopaedic surgeons in the care of elbow disorders. One evaluator (DMR) re-examined all images after the first examination in order to minimize observer recall bias. The data was recorded patient age, side, diagnosis, PUDA, and tip- to apex distance.

2.3 Statistical methods
Side to side comparison of the PUDA and the tip-to-apex distance in the same subject was assessed using the pearson correlation and a paired t test, and the t test was used to compare the average PUDA between men and women. The significance level of 0.05 was used for the t test. Statistical analysis was performed by using SPSS 16.0 software.

3. Results
The mean age of male and female patients has no significant differences in terms of gender distribution. The data of recorded measurements were analysed, it was observed 92% of the radiographs presents PUDA. The average PUDA was 5.6 on right elbow and 5.1 on left elbow respectively. The range of PUDA was 1.4 to 12 on the right elbow and the range of PUDA on left side was 0-11.5. The right elbow shows average tip-to-apex distance was 45mm and the left elbow average tip-to-apex distance was 48mm. The correlation between left and right with gender differences of PUDA was summarized in table I. The average PUDA of right elbow was 5.6 in men and 5.5 in women. The mean gender difference was not significant for the right side, but it was significant for the left side. The mean tip-to-apex distance was 43 mm on the right and 42 mm on the left in women, and 45 mm on the right and 48 mm on the left in men. While comparing the mean values of the tip-to-apex distance between men and women, distance from the olecranon tip to apex of the PUDA was significantly greater in men.

Table I: Proximal Ulna dorsal angulation and tip-to-apex distance measurements

Measurements		Right			Left		
		Range	Average	SD	Range	Average	SD
PUDA	Male	1.4 - 12	5.6	2.1	0-11.5	5.4	2.0
	Female	1.2-11.8	5.5	2.7	0-11.2	5.1	1.9
Tip-to-apex distance (mm)	Male	35.4-60.2	45	5.6	32-61.3	44	5.2
	Female	34 -66.8	43	6.3	33.1-62.4	48	6.9

Fig 1: A lateral radiographs of elbow showing PUDA between tangent lines placed on the dorsal aspect of the olecranon and the dorsal ridge of the ulnar shaft.

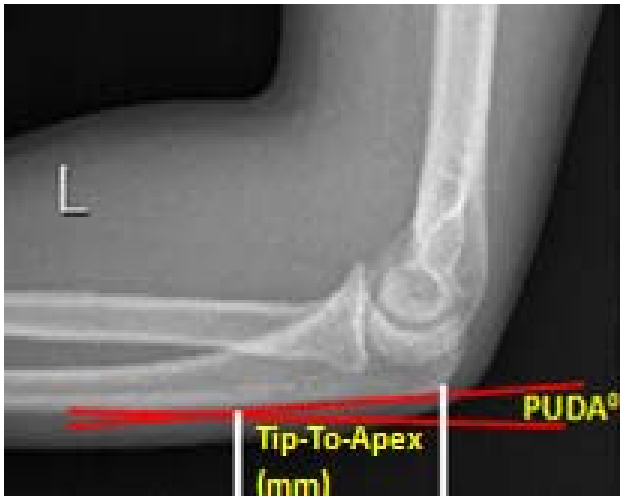

Fig 2: A lateral radiographs of elbow showing location of the apex of the PUDA.

4. Discussion

The computed images, cadavers are used for dorsal angulation of proximal ulna studies. Cadaveric studies have some limitations, as it does not give much detail about elbow and proximal ulnar anatomy. The reliability of measurements taken on cadaveric elbow is also questionable. Magnetic CT images are used for some studies have advantage over radiographic images. However, measurements of different parameters taken in radiographic study are fair reliable as same as magnetic images. It is important to restore proximal ulnar anatomy after fracture or osteotomy. Malunion of the proximal ulna can lead to maltracking of the radial head, incongruity of the proximal radio-ulnar joint, and abnormal rotation of the forearm [7].

The findings of our current study suggest that the apex of dorsal angulation of ulnar in radiographs is located relatively more distal. When comparing the relationship between age and the measured parameters, the tip-to-apex length of the ulna increased as age advanced, but age was not related to angles or percentage distances. In the gender comparison, the tip-to-apex distance of left elbow in females was greater than in males. Sex did not have a significant on any of the other measurements. Dumont *et al*. [3], described significant variability in the side-to-side measurement of torsional alignment of the ulna with cross-sectional magnetic resonance imaging. The authors had undertaken volunteers for the study to examine the overall torsion of the ulna from a single point on the distal humerus to a single point on the ulnar head. The location and magnitude of the torsion was not reported in the study.

An anatomic study with relevance to olecranon osteotomy and fracture fixation done on 39 paired elbows by wang [8]. The measurements described in the study were ulnar length, the bare area of the sigmoid notch, lateral varus angulation, and ulnar cortical dimensions. Even though paired specimens were used, the authors did not report the side-to-side correlations. The characteristics reported in the study were useful to assist the planning of olecranon osteotomies and fracture fixation. Akpinar *et al*. [9], studied the anatomic factors of the proximal ulna that would simplify intramedullary nail insertion for fracture fixation. The researchers identified an optimum site for nail entry, intramedullary canal diameter, and canal length.

The results of current study showed a mean PUDA of 5.6, it was located 45 mm distal to the tip of the olecranon. Goldberg SH *et al*. [10], studied on 54 cadaveric ulna and reported an average PUDA of 4.5, these findings are in comparison with the results of our study. The PUDA of side to side comparison was not reported by the authors. In our study, the radiographic measurement of the PUDA and the distance from tip of olecranon to apex of PUDA is good reliable, as fair to excellent intraobserver and interobserver reliability. Statistical analysis of data demonstrates mean tip-to-apex distance was not significant between right and left correlation. The distance for olecranon tip to the apex of the PUDA was significant in gender correlation. Similar results reported by Mall *et al*. [11] and Matzon *et al*. [12]. The literature of authors demonstrates gender differences in the length and width of the ulna. Wadia *et al*. [13], studied on radiographic measurement of normal elbows reported that gender differences for the PUDA were equivocal, with differences approaching statistical significance only on one side. The novel information in the study is side-to-side symmetry, as the distance of the apex of the angulation from the olecranon tip.

5. Conclusion

The radiographic study on bilateral elbow reveals proximal dorsal angulation of ulna measurements for selection of ideal plates for proximal ulna fracture fixation. Both tip-to-apex distance and angulations are crucial landmarks for orthopaedic surgeons when applying plates and attempting to perform total elbow replacement surgery. The data provided in the current study is valuable information as most of the commercially available precontoured anatomic dorsal ulna plates are straight and it cannot incorporate the PUDA. The study summarise the high reliable PUDA measurements and the excellent side-to-side correlation may permit us to make a recommendation to medical manufacturers for modelling ulna plates and other components of artificial elbow joints.

The observers recommended that radiographic image findings alone are not sufficient while making treatment decisions regarding the correction of rotational malunions, deformities due to multiple hereditary exostosis.

6. Acknowledgement

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