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Surgical Importance of Radiographically Aided Morphometry of the Proximal Ulna

Importancia Quirúrgica de la Morfometría de la Ulna Proximal con Examen Radiográfico

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SUMMARY: This study was conducted to define the proximal ulnar morphometry with respect to dorsal and intramedullary implant design. Eighty two dry Anatolian ulnae were evaluated by both the traditional and digital morphometric analysis methods. Also the medullary cavities and cortical bone thicknesses were measured from radiographic images. The mean value of ulnar length (UL) was 25.06 cm; distance between the most prominent anterior point of the superior surface of the olecranon (MAPO) and the most posterior point of the olecranon (MPPO), distance between the MPPO and maximum anterior angulation (MAA), distance between the MPPO and the maximum varus angulation (MVA) were; 1.67 cm, 5.36 cm and 7.56 cm, respectively. The average antero-posterior diameters at mid-olecranon plane (MOP), MAA plane (MAAP) and MVA plane (MVAP) were; 1.78 cm, 1.68 cm and 1.41 cm; transverse diameters of same planes were; 1.96 cm, 1.65 cm and 1.51 cm, respectively. The mean olecranon angle (OA), MAA and MVA were: 113.35°, 9.12° and 13.82°; also the mean circumferences at same planes were 6.48 cm, 6.37 cm and 5.16 cm, respectively. The mean antero-posterior medullary diameter at MAAP and mean transverse medullary diameter at MVAP were; 6.83 mm and 7.22 mm, respectively. Mean anterior and posterior cortical bone thicknesses at MAAP were: 3.61 mm and 4.25 mm; the mean medial and lateral cortical bone thicknesses at MVAP were: 4.06 mm and 4.13 mm, respectively. Dorsal angulation and medullary angulation of the proximal ulna presents different architecture. Unique morphological architecture of the proximal ulna should be taken into consideration in means of surgical operations and examination of radiographic images. It can be inferred that standardized bony landmarks may helpful during the process of designing and manufacturing precurved dorsal plates and as well as variable proximal ulnar implants.

KEY WORDS: Anatomy; Morphometry; Proximal ulna; Radiography; Varus angulation.

INTRODUCTION

The displaced proximal ulna and the olecranon fractures are mostly stabilized by dorsal plates (Beser *et al*., 2014; George & Lawton, 2015; Melamed *et al*., 2015). The proximal and upper thirds of the ulnar fractures are surgically treated with open reduction and internal fixation In some cases if the fragments are not displaced, a simple splint immobilizing the forearm and preventing the elbow joint movements is adequate for rehabilitation (Brownhill *et al*., 2009). Variability of the fractures determine the suitable implants such as plates (double or single), intramedullary nails, intramedullary screws and tension band wires (Brownhill *et al*.; Hong *et al*., 2015; Niéto *et al*., 2015; Fuller, 2016). Each implant can maintain its stiffness and stability when properly selected (Windisch *et al*., 2007a,b; Melamed *et al*.). Several factors such as intensive daily activities, inappropriate implant design and misalignment of the implants cause loosening of the implant components (Brownhill *et al*.; Kim *et al*., 2011). Commercially manufactured implants are mostly compatible with the dorsal surface of the proximal ulna. But if the implants do not fit properly to the proximal ulnar architecture, it is not possible to easily bend them due to the material compounds (Hewins *et al*., 2007; Brownhill *et al*.; Totlis *et al*.). However the unique structure of the proximal ulna challenges both the surgeons and the radiologists (Cowal & Pastor, 2008). Anatomically curve-shaped architecture of proximal ulna affects the functional recovery due to using pre-curved dorsal plates (Brownhill *et al*.).

Another important issue is the diameter of the ulnar cavity and the thickness of the cortical bone at proximal ulnar angulations (Grechenig *et al*., 2007). An intramedullary nail applied from superior surface of the olecranon is passing through these angles and stabilize the proximal ulnar frac-

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tures (Windisch *et al*., 2007a). Extensive morphological literature data particularly the wall thickness and diameter at angulations of curve shaped proximal ulna is insufficient. Having detailed knowledge of the wall thickness and diameter of the cavity at angulations, present substantial data that play a key role in implant design and surgical interventions (Akpinar *et al*., 2003).

In this study it was aimed to investigate the detailed proximal ulnar morphometry of 82 dry ulnae (39 right, 43 left). For this purpuse 22 morphometric parameters were defined. The morphometric differentiations and the relations were analyzed. Also the proximal ulnar radiographies obtained from the same dry ulnae were evaluated to determine the diameters of the cavity and the cortical bone thickness at angulations.

MATERIAL AND METHOD

Well preserved 82 (39 right, 43 left) dry Anatolian ulnae obtained from the Department of Anatomy, Medical Faculty, Cukurova University (Adana, Turkey) were examined: the age and sex of the specimens were unknown. Certain landmarks were marked by a boardmarker before the measurements: the most prominent anterior point of the superior surface of the olecranon (MAPO), the most posterior point of the olecranon (MPPO), the point of the maximum anterior angulation (MAA), and the point of the maximum varus angulation (MVA) (Fig. 1). In addition, the mid-anterior, mid-posterior, mid-medial and mid-lateral surfaces of the olecranon were marked and bonded by a single line to create a circle.

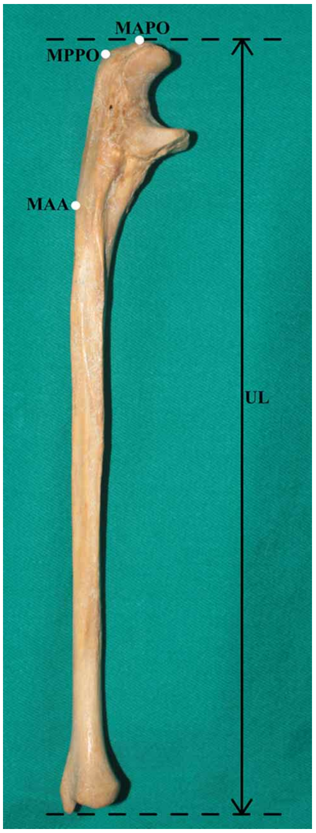

Fig. 1. UL: Ulnar length. MAPO: Most prominent anterior point of the superior surface of the olecranon. MPPO: Most posterior point of the olecranon. MAA: Maximum anterior angulation.

Following distances were measured by a digital sliding caliper (accurate to 0.01 mm): ulnar length (UL), distance between the MAPO-MPPO, distance between the MPPO-MAA, distance between the MPPO-MVA (Fig. 1). Also the antero-posterior and transverse diameters of certain planes were measured by the same caliper: mid-olecranon plane (MOP), the maximum anterior angulation plane (MAAP) and the maximum varus angulation plane (MVAP) (Figs. 2A and 2B).

Since digital analyses promise more precise measurements and the angulations of proximal ulna gradually curved, the angles were measured from digital photographs with an image analysis software (Digimizer, Japan). A DSLR camera (Canon 5D Mark III, Japan) with an objective (Canon EF 50mm f/1.4 USM Lens, Japan)

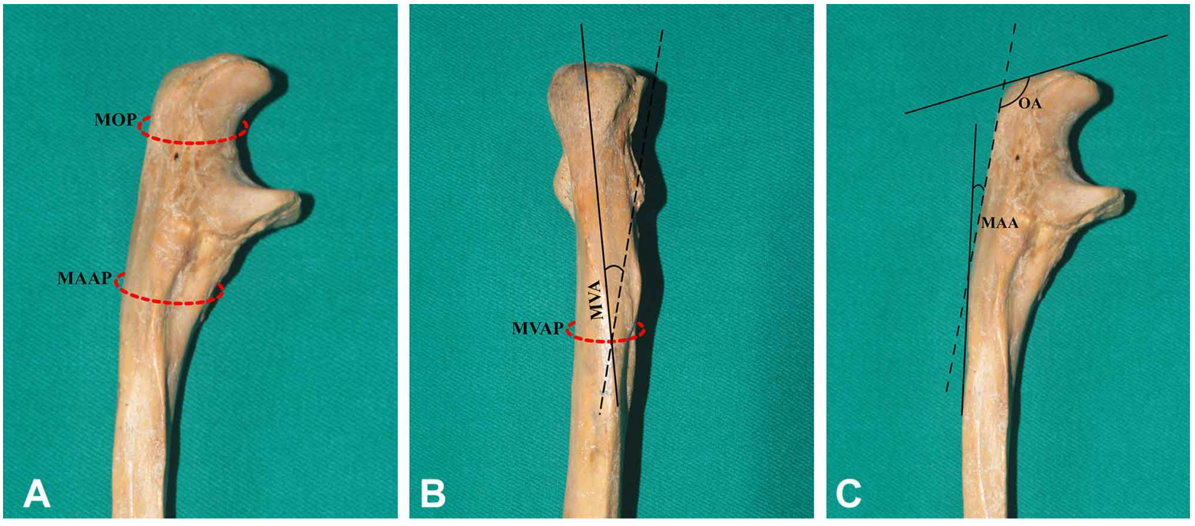

Fig. 2. A. MOP: Mid-olecranon plane. MAAP: Maximum anterior angulation plane. B. MVA: Maximum varus angulation. MVAP: Maximum varus angulation plane. C. MAA: Maximum anterior angulation. OA: Olecranon angle.

were used. The camera fixed with a tripod than placed 2 meters away and positioned 90° to specimens; one pair of paraflashes were lightened the specimens. The distortions were prevented by using proper exposure values (50 mm, f:2.8). On the photographs MAPO, MPPO, MVA, MAA points were also marked digitally. Angle of olecranon (OA) was measured between the intersection of the MAPO-MPPO and MPPO-MAA lines which tangenital to dorsal surface of the ulna (Fig. 2C). Maximum anterior angulation were measured from the intersecton of the lines tangential to dorsal surface of proximal and distal ulna (Fig. 2C). Maximum varus angulation: was measured from intersection of superior and inferior midshafts (Fig. 2B).

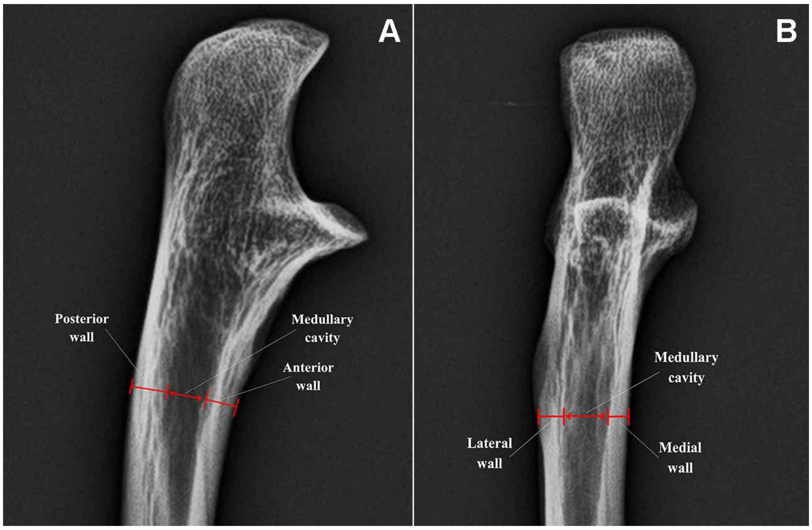

Fig. 3. Medullary cavities and cortical bone thicknesses at MVAP (A) and MAAP (B).

The circumferences were measured by an non elastic tape measure from mid-olecranon plane (MOP), maximum anterior angulation plane (MAAP) and the maximum varus angulation plane (MVAP) (Figs. 2A and 2B).

The medullary cavity and the thickness of the cortical bone at angulated points were measured from antero-posterior and lateral radiographies of the ulnae by the image analysis software (Digimizer, Japan) (Figs. 3A and 3B).

Stastical analysis were evaluated by SPSS 20.0.

RESULTS

The mean values of: ulnar length (UL) was 25.06 cm; distance between the MAPO and MPPO, distance between the MPPO and MAA, distance between the MPPO and MVA were: 1.67 cm, 5.36 cm and 7.56 cm, respectively (Table I). The average antero-posterior diameters at MOP, MAAP and MVAP were: 1.78 cm, 1.68 cm and 1.41 cm; transverse diameters of same planes were 1.96 cm, 1.65 cm and 1.51 cm, respectively (Table II).

Table I. Proximal ulnar osteometric data

Parameters (cm)	Range (n)	Mean (SD)
UL	20.47 – 20.94 (82)	25.06 ± 1.75
MAPO - MPPO	1.04 – 2.37 (82)	1.67 ± 0.26
MPPO - MAA	2.99 – 9.13 (82)	5.36 ± 1.16
MPPO - MVA	5.59 – 9.61 (82)	7.56 ± 0.83

UL: Ulnar length; MAPO: Most prominent anterior point of the superior surface of the olecranon; MPPO: Most posterior point of the olecranon; MAA: Maximum anterior angulation; MVA: Maximum varus angulation.

The mean OA, MAA and MVA were: 113.35°, 9.12° and 13.82°; also the mean circumferences at same planes were 6.48 cm, 6.37 cm and 5.16 cm, respectively (Table III).

The mean transverse medullary diameter at MAAP and mean antero-posterior medullary diameter at MVAP were; 6.83 mm and 7.22 mm, respectively (Table IV). Mean anterior and posterior cortical bone thicknesses at MAAP were: 3.61 mm and 4.25 mm; the mean medial and lateral cortical bone thicknesses at MVAP were: 4.06 mm and 4.13 mm, respectively (Table V).

Evaluated parameters did not reveal a significant difference between left and right sides (p>0.05).

Table II. Data of antero-posterior and transverse diameters.

	Antero-posterior Diameters (cm)		Transverse Diameters (cm)	
Parameters	Range (n)	Mean (SD)	Range (n)	Mean (SD)
MOP	1.24 – 2.19 (82)	1.78 ± 0.18	1.45 – 2.55 (82)	1.96 ± 0.20
MAAP	1.16 – 2.70 (82)	1.68 ± 0.31	1.13 – 2.15 (82)	1.65 ± 0.22
MVAP	0.85 – 1.87 (82)	1.41 ± 0.19	1.14 – 1.92 (82)	1.51 ± 0.18

MOP: Mid-olecranon plane; MAAP: Maximum anterior angulation plane; MVAP: Maximum varus angulation plane.

Table III. Angles and circumferences at certain landmarks.

	Angles (°)		Circumferences (cm)	
Parameters	**Range (n)**	**Mean (SD)**	**Range (n)**	**Mean (SD)**
OA	95.99 – 132.85 (82)	113.35 ± 7.83	5.60 – 7.50 (82)	6.48 ± 0.43
MAA	0.50 – 17,67 (82)	9.12 ± 4.35	4.70 – 7.80 (82)	6.37 ± 0.67
MVA	5.07 – 21.04 (82)	13.82 ± 3.36	4.10 – 6.00 (829	5.16 ± 0.49

OA: Olecranon angle; MAA: Maximum anterior angulation; MVA: Maximum varus angulation.

Table IV. Diameters at angulations.

Parameters (mm)	Range (n)	Mean (SD)
MAAP antero-posterior	2.35 – 13.49	6.83 ± 2.08
MVAP transverse diameter	3.40 – 13.06	7.22 ± 2.08

MAAP: Maximum anterior angulation plane; MVAP: Maximum varus angulation plane.

Table V. Cortical bone thicknesses at angulations.

Cortical bone thickness (mm)	Range (n)	Mean (SD)
MAAP anterior wall	1.57 – 6.94	3.61 ± 1.06
MAAP posterior wall	1.83 – 7.36	4.25 ± 1.23
MVAP medial wall	1.23 – 6.41	4.06 ± 1.07
MVAP lateral wall	1.48 – 6.56	4.13 ± 0.95

MAAP: Maximum anterior angulation plane; MVAP: Maximum varus angulation plane.

DISCUSSION

The complex anatomical componenets of the elbow joint consists of ulnohumeral, proximal radioulnar and radiocapitellar joints (Rouleau *et al*., 2010). These joints allow fundamental movements by acting together: flexion, extension and prosupination (Hewins *et al*.). During these movements rotational and torsional forces influence the elbow joint (Dounskaia & Wang, 2014). Various ligaments, tendons and muscles extremely stabilaze this important joint (Pereira, 2013). However direct or indirect trauma causes fractures of the proximal ulna and affects the elbow joint movements (Windisch *et al*., 2007a). Displaced proximal ulnar fractures must be treated by stabilization implants that compatible the fracture pattern (Rouleau *et al*., 2010; Beser *et al*.). The proximal ulnar morphometry should be considered in order to avoid misalignment, malunion, incompatibility of the elbow joint components, and abnormal rotational or flexion movements (Rouleau *et al*., 2010).

In the present study the mean MAA was found as 9.12°. Grechenig *et al*., Totlis *et al*. and Beser at al. studied on dry ulnae and reported an average MAA angle of 4.5°, 8.49° and 8°, respectively. Roulea *et al*. (2012) measured the proximal ulna dorsal angulation (PUDA: same MAA parameter with different definition) on radiographies of healty volunteers and reported a mean 5.2° value. Puchwein *et al*. (2012) found 6.2° mean MAA value from 3D digital elbow joint models which reconstructed from CT scans belongs to 30 cadeveric and 10 younger patients' elbow joints. As is clear from the investigated MAA data in the literature, the difference between these values are confusing. Because nor a single MAA or MVA point may not be determined due to gradually deviation of the proximal ulna.

Also the MVA values represent diversity in the literature. While the average MVA was found 13.82° in this study, Beser *et al*. and Totlis *et al*. found 9.3° and 8.48°, respectively (both scientific teams evaluated the proximal ulnar morphometry on dry ulanae as in the current study). Greching *et al*. (2007) and Windisch *et al*. (2007a) conducted different cadaveric studies to characterise the proximal ulnar morphometric features and found similar mean MVA values (17.7° and 17.5° respectively). Windisch *et al*. (2007b) also reported the varus angulation of the medullary cavity as 8.95° in another study at the same year. The maximum varus angulation presents significant difference between the medullary cavity and the posterior margin. Puchwein *et al*. found a similar MVA value (14.3°). Totlis *et al*., Beser *et al*. and Windisch *et al*. (2007b) were aimed to investigate the long axis angulation of the proximal ulna as in the present study. However there is a slight difference between mean MVA values since proximal ulna shows gradual angulations (Beser *et al*.; Totlis *et al*.).

The mean distance between the MPPO and MVA was 7.56 cm in the present study. Although the definitions of the most posterior point of the olecranon (MPPO) were varied in the literature, the results indicate close values (Grechenig *et al*.; Windisch *et al*., 2007,b; Beser *et al*.; Totlis *et al*.). While Wang *et al*. (2003), and Grechenig *et al*. were defined this morphometric length as distance between the triceps insertion and the point of varus angulation (MVA), the other authors defined this particular distance as in the present study. It is surprising whether the distance between the MPPO and MVA was investigated on cadavers or on dry ulane, the results did not appear to be influenced by the specimen choice. Also the different definitions may not truly be influential on the results.

The average olecranon angle (OA) was 113.35° in this study. Puchwein *et al*. and Totlis *et al*. found the OA;

110.34° and 95.3° respectively. While the mean olecranon length was found 1.67 cm in the present study, Puchwein *et al*. found this distance 1,58 cm and Totlis *et al*. found it 2.47 cm. In this study and the study of Puchwein *et al*., the most prominent anterior point of superior surface of the olecranon (MAPO) was used as a landmark. However Totlis *et al*. used the anterior olecranon tip as a landmark to measure the olecranon length. The anterior olecranon tip is slightly distant and lower from the MAPO. The precurved dorsal plates placed on the dorsal surface of the proximal ulna, extend to the most prominent anterior point of superior surface of the olecranon (MAPO). Therefore, in this study MAPO was determined as landmark because it was aimed to perform morphometric evaluations compatible for implant design.

Proximal ulna shows unique structural angulations (varus and anterior angulations) and these angulations cause undeniable variations between individuals (Windisch *et al*., 2007b; Beser *et al*.; Adikrishna *et al*., 2016). It is assumed that not only angulations of the morphometric features of the ulna influenced by demographic characteristics, but also and physical activities (repititive and force required actions) (Claussen, 1982). However it has not been clear whether demographic characteristics or the variations affect the proximal ulnar pathologies. In addition, the discrepancy of values in the literature may vary by the different definition of the landmarks (Windisch *et al*., 2007b; Puchwein *et al*.; Totlis *et al*.; Beser *et al*.; Adikrishna *et al*.). For example; proximal ulna shows a gradual anterior deviation, starting from the middle and proximal one-third of the ulna and becomes more prominent proximally at the metaphysis (Siebenlist *et al*., 2019). The fact that a single landmark for MAA can not be choosen by all researchers globally and this can lead to differences which can be reasonably observed.

The evaluated measurements, especially the proximal ulnar angulation data, not only may help in the process of designing and modifying prosthesis and preshaped ulnar implants but also can contribute to the accumulation of knowledge that surgeons, radiologists, anthropologists and the anatomists can benefit. In addition, it has been clearly understood that common definitions and landmarks should be determined for the standardized examination of proximal ulnar morphometry.

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RESUMEN: Este estudio se realizó para definir la morfometría ulnar proximal con respecto al diseño de implante dorsal e intramedular. Ochenta y dos ulnas de Anatolia secas fueron evaluadas por los métodos de análisis morfométrico tradicional y digital. También se midieron las cavidades medulares y el grosor del hueso cortical a partir de imágenes radiográficas. El valor medio de la longitud ulnar (LU) fue de 25,06 cm; distancia entre el punto anterior más prominente de la superficie superior del olécranon (SSO) y el punto más posterior (PPO), la distancia entre el PPO y la angulación anterior máxima (AAM), la distancia entre el PPO y la angulación máxima en varo (AMV) fueron; 1,67 cm, 5,36 cm y 7,56 cm, respectivamente. Los diámetros anteroposteriores medios en el plano medio del olécranon (PMO), el plano AAM (AAP) y el plano AMV fueron; 1,78 cm, 1,68 cm y 1,41 cm; los diámetros transversales de los mismos planos eran; 1,96 cm, 1,65 cm y 1.51 cm, respectivamente. El ángulo medio del olécranon (AMO), AAM y MVA fueron: 113,35 °, 9,12 ° y 13,82 °; También las circunferencias medias en los mismos planos fueron 6,48 cm, 6,37 cm y 5,16 cm, respectivamente. El diámetro medular anteroposterior medio en AMV y el diámetro medular transversal medio en AMV fueron; 6,83 mm y 7,22 mm, respectivamente. Los grosores óseos corticales anteriores y posteriores medios en AMV fueron: 3,61 mm y 4,25 mm; Los espesores medios de los huesos corticales medial y lateral en AMV fueron: 4,06 mm y 4,13 mm, respectivamente. La angulación dorsal y la angulación medular de la ulna proximal presentan una arquitectura diferente. La arquitectura morfológica única de la ulna proximal debe tenerse en cuenta en las operaciones quirúrgicas con el examen de imágenes radiográficas. Se puede inferir que los puntos de referencia óseos estandarizados pueden ser útiles durante el proceso de diseño y fabricación de placas dorsales precurvadas y también de implantes ulnares proximales variables.

PALABRAS CLAVE: Anatomía; Morfometría; ulna proximal; Radiografía; Angulación en varo.

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