Positioning of longest axis of the radial head in neutral forearm rotation

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Abstract

Introduction: The radial head has an ellipsoid shape so that a longest and a shortest axis can be defined. The aim of this study is to evaluate the position of the longest axis of the radial head (LARH) in relation to proximal radioulnar joint (PRUJ) and to the forearm in neutral position using 3D computed tomography (CT).

Materials and methods: 3D CT reconstructions of the distal humerus, the radius and the ulna of 27 healthy volunteers (average age 27.65 ± 9.25 ; 24 males, 3 females) were created. First an evaluation of the elliptic form of the radial head and the location of its longest axis was performed. Next, three planes were defined: the PRUJ plane, the forearm plane and a neutral plane. Based on the angle between the forearm plane and the neutral plane, the rotation of the scanned forearm was measured. Taking this rotation into account, the position of the LARH compared to PRUJ plane and forearm plane in neutral position is recalculated.

Results: The shape of the radial head is determined to be non-circular based on this study population ($p < .001$). In neutral position, the angle between the LARH and the forearm plane is 5.28° (SD: 15.09) and between the LARH and the PRUJ is 33.46° (SD: 13.91).

Conclusions: The position of the LARH is found to be approximately perpendicular to the forearm plane when the forearm is in neutral position and perpendicular to the PRUJ plane when the forearm is on average in 30° of pronation.

Keywords

radial head, non-circular, neutral rotation, 3D reconstructed, CT, proximal radioulnar joint

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Introduction

The range of motion of the forearm rotation is approximately 180° and typically involves three joints, namely the proximal and distal radio-ulnar joints (PRUJ and DRUJ) and the humeroradial joint. In the DRUJ, the radius articulates with the ulnar head whereas in the PRUJ the radial head, surrounded by the annular ligament, articulates with the radial notch of the ulna. At the humeroradial joint, the fovea radialis of the radial head articulates with the humeral capitellum. A cadaver study by van Riet et al described that the radial head is most commonly an ellipse, defined by a long axis of the radial head (LARH) and a short axis (SARH).¹ As a consequence, the orientation of the longest axis of the radial head compared to the radial notch of the ulna changes during rotation of the forearm. The orientation of the radial head towards the radial notch of the ulna

is important, as a conflict at the PRUJ can limit pronation-supination.² To our knowledge, the correlation between the forearm rotation and the position of the LARH towards the radial notch of the ulna, has only been studied on cadavers. Our study aims to evaluate this correlation more accurately, based on 3D CT reconstructions of forearm.

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Materials and methods (Ethics committee B670201524945)

A total of 27 Caucasian volunteers (mean age: 27.65 ± 9.25 ; 24 males, 3 females) received a Computed Tomography (CT) scan of the distal humerus, complete forearm and proximal row of the wrist. No clinical or radiological abnormalities were

encountered. In order to achieve a standardized protocol, exclusively the left side was scanned using a Siemens SOMATOM Definition AS (Siemens, München, Germany). The obtained CT images had a voxel size of $0.45 \times 0.45 \times 0.6$ mm, with 0.6 mm being the slice thickness.

Using an imaging software package (Mimics 19.0[®] and 3-matic 11.0[®] (Materialise, Leuven, Belgium)), anatomical 3D reconstructions of the distal humerus, the radius and the ulna were made. On the 3D reconstruction of the radius, the peripheral rim of the radial head was marked and the best fitting plane through this marked region was defined as the radial plane (RPlane) and the 2D CT-scan were reconstructed using that plane as reference. In the axial 2D CT images the radial head was manually fully encircled (Figure 1). Subsequently, the longest axis (LARH) and the shortest axis (perpendicular to the longest axis) (SARH) were defined automatically, with the center of the radial head (CR) defined as their intersection (Figure 1). The shape of the radial head was evaluated by comparing the length of the LARH and SARH is evaluated (DiffAxes).

The rotational orientation of the radial head was determined. The proximal radio-ulnar joint (PRUJ) was defined as a plane defined by three points: the most anterior and posterior corners and the most inferior point of the radial notch. Next, an x-y reference system was developed with CR at point zero. The y-axis was defined as the intersection between the RPlane and a plane parallel to the PRUJ plane through CR. The x-axis was perpendicular to the y-axis in the radial plane and through CR (Figure 2).

The relative position of each bone of the elbow joint, e.g. the humerus, the radius and the ulna, was considered by the construction of a plane through each

Figure 1. Definition of the longest axis and the short axis (perpendicular to the longest axis).

Figure 2. PRUJ plane: (a) the two outermost points of the radial notch are indicated (pu1, pu2) with an x-y reference system. (b) 3D visualization of the PRUJ plane.

bone, in order to define the amount of pronation and supination. The humeral plane was based on the center of the capitellum, the medial side of the trochlea and the thinnest point of the humerus on sagittal view (Figure 3).

A neutral plane is defined perpendicular to the humeral plane and through the pronation-supination axis. Two reproducible points defined the pronation-supination axis. The first point was the center of the best fitting sphere of the distal ulnar head is (3-matic) (Figure 4). The second point was, in contrast to literature, defined by the center of the capitellum and not the center of the radial head.³ With this technique the pronation-supination axis was displayed as a line connecting the centers of two spheres around which the radius could rotate.

The plane perpendicular to the humeral plane and going through the centers of the two spheres was defined as the neutral plane (Figure 5).

The forearm plane was defined as the plane going through the center of the two spheres and the radial process styloideus (Figure 5).

In the elbow, the position of the radius was defined as supination (+) if the radial process styloideus was lateral in comparison to the neutral plane and in pronation (–) if the radial process styloideus was medial in comparison to the neutral plane (Figure 5). The amount of pronation or supination was measured as the angle (angle Prosup) between the neutral plane and the forearm plane (Figure 5).

This angle (angle Prosup) needed to be considered when evaluating the angle between the LARH and the x-axis (angle LARH-X) (Figure 6). The evaluation of the angle LARH-X was measured with the forearm in neutral position. Therefore, the angle Prosup was subtracted from/added up to the measured angle LARH-X

Figure 4. Pronation-supination axis defined by the center of the best fitting sphere of the capitellum and the center of the best fitting sphere of the distal ulna.

Figure 5. Measurement of the pronation-supination angle in the distal forearm as the angle between the forearm plane and the neutral plane.

Figure 3. Humeral plane. (a) The centre of capitellum (b) the centre of the best fitting circle at the medial border of the trochlea (c) the upper most smallest point.

Figure 6. Measurement of angle LA in the proximal forearm as the angle between the longest axis and the neutral plane.

depend on the imaginary rotation needed to bring the forearm to neutral position. In case of a supinated left arm, the LARH was turned clockwise, looking from superior. In case of a pronated arm, the LARH was turned counterclockwise. After this adaptation, the angle between the LARH and the x-axis was the corrected angle LARH-X. The second null hypothesis was that the corrected angle LARH-X was 0° and as a consequence the LARH is in neutral position perpendicular to the PRUJ plane.

To evaluate whether the LARH was perpendicular to the forearm in neutral rotation the difference between the PRUJ plane and the neutral plane was determined (angle PRUJ-Neu). Therefore, in the radial plane, the corrected angle LARH-X was adjusted with the angle PRUJ-Neu (angle LARH-Neu). The position of the radius was defined as supination (+) and pronation (-), similar to the previously used technique. The third null hypothesis was that the angle LARH-Neu is 0° and as consequence the LARH was perpendicular to the forearm plane in neutral position.

Statistical analysis

The data analysis was performed with SPSS 23.0® (IBM, New York, United States of America). Measurements are taken from each individual CT scan and all resulting variables are reported as mean $\pm$ standard deviation (SD). The inter- and intraclass correlation coefficient (ICC, two-way random, absolute agreement) was determined to

Table 1. Length of the long axis, the short axis and the difference between both.

	Minimum (mm)	Maximum (mm)	Mean (mm)	Standard deviation (mm)
LARH	20.78	27.28	23.95	1.73
SARH	17.89	25.35	21.86	1.85
DiffAxes	0.50	4.02	2.08	0.82

LARH: long axis of the radial head; SARH: short axis of the radial head.

evaluate the reproducibility of the chosen planes. An ICC larger than 0.70 was evaluated as good reproducibility. A paired sample student t-test was used for evaluation of the rounded shape. For data interpretation, an α -value for statistical significance of 0.05 was used. The correlation between the LARH and SARH was measured using the Pearson correlation coefficient.

Results

We found excellent interobserver reliability for all planes with an ICC value of 0.91 (95% CI: 0.83 to 0.95) for the humeral plane, 0.94 (95% CI: 0.83 to 0.98) for the radial plane, 0.79 (95% CI: 0.50 to 0.93) for the neutral plane and 0.98 (95% CI: 0.97 to 0.99) for the PRUJ plane. With regards to the intraobserver reliability, we again found excellent intraobserver reliability with an ICC value of 0.92 (95% CI: 0.84 to 0.96) for the humeral plane, 0.94 (95% CI: 0.83 to 0.98) for the radial plane, 0.82 (95% CI: 0.63 to 0.98) for the neutral plane and 0.97 (95% CI: 0.95 to 0.99) for the PRUJ plane. The descriptive statistics of the length of the LARH, SARH and DiffAxes can be seen in Table 1 and Figure 7.

There is a significant difference between the LARH and SARH ($p < 0.001$). The LARH has a correlation of 0.897 with the length of the SARH.

The corrected angle LARH-X can be seen in Table 2. There is a significant difference between the corrected angle and 0° ($p < 0.001$). Therefore, the LARH is not perpendicular to the PRUJ plane in neutral rotation.

On average the angle PRUJ-Neu is 28.18° (SD 7.11°) (Table 2). This means the plane of the PRUJ is not parallel but is always pronated compared to the neutral plane. There is no significant difference between the angle LARH-Neu and 0° ($p = 0.329$, stating a perpendicular relationship between the LARH and the forearm plane in neutral rotation).

Figure 7. The length of the long axis of the radial head compared to the length of the short axis.

Table 2. The measured angles describing the absolute position of the radius in comparison to the ulna and humerus.

	Minimum (°)	Maximum (°)	Mean (°)	Standard deviation (°)
Corrected angle LARH-X	-5.37	63.09	33.46	13.91
Angle PRUJ-Neu			28.18	7.11
Angle LARH-Neu			5.28	15.09

LARH: long axis of the radial head; PRUJ: proximal radioulnar joint.

Discussion

The position of the LARH is found to be perpendicular to the forearm plane when the forearm is in neutral position and perpendicular to the PRUJ plane when the forearm on average in 30° of pronation.

To obtain these results we used a quantified measurement technique to evaluate the three-dimensional relationship between the humerus, radius and ulna. This study demonstrates that this measurement technique, using in vivo three-dimensional CT reconstruction, demonstrated a low variability. The different planes showed a high inter and intra-observer reliability.

In contrast to other articles we defined the pronation-supination axis based on the center of the ulnar head and center of the capitellum and not on the center of the radius.³ In the DRUJ, the ulnar head can be seen as a part of a sphere with a clear center

of rotation. In the humero-radial joint, also the morphology of the capitellum is spherical and a clear center of rotation can be defined. This means the axis around pronation-supination is fixed and defined by two non-moving centers of two spheres around which the radial bone can rotate and is independent of the shape of the radial head. When the pronation-supination axis would be defined by the center of the radial head, the pronation-supination axis would not be fixed because the center of the non-circular radial head is moving.

As described in several studies the most common form of the radial head is non-circular and this is also confirmed in our study.¹ The elliptical shape provides the radial head to give more radio-ulnar space during pronation, allowing the passage of the radial tuberosity and its tendinous attachment.⁴ This theory is confirmed by the fact that when the radial head is circular, the angle between the neck and the radial diaphysis is more prominent and this can be seen as an adaption for the radial head not being elliptical.⁴ The importance of the radio-ulnar space has also been demonstrated by the study by Bhatia that demonstrated that the space reduces significantly from the fully supinated to the fully pronated position.⁵

This elliptic form also has its consequence of the humero-radial joint. From biomechanical point of view, it has been described that different orientations of the longest axis of the noncircular radial head will result in different forces in the humero-radial joint.^{6,7}

Our study demonstrated that the longest axis is perpendicular to the forearm plane in neutral position but not perpendicular to PRUJ plane. The PRUJ plane is situated at an average of 30° pronation compared to the neutral plane.

This difference confirms the cadaveric observations of Weiss and Hastings⁸ but is in contrast with the results of cadaveric observations report by Van Riet.¹ Van Riet et al described that the position of LARH is perpendicular to the radial notch of the ulna, in the neutral pronation-supination position and this position is currently advised in the surgical technique of non-circular radial head arthroplasty.¹

This difference in observation may be important from clinical point of view when using an elliptical radial head implant. The elliptic shape of the prosthesis implicates that the orientation of the longest axis should be considered when implanting the device. Based on our study we would propose to position the longest axis of the implant perpendicular to the forearm in neutral rotation. This is in contrast to the current described surgical technique of the noncircular radial head arthroplasty in the market.⁹ However currently it is not clear if this 30° of rotation difference has a biomechanical importance or will influence the clinical outcome.

A possible weakness of the study is the fact that all measurements were performed on young people and not on CT scans of an older population in which radial head arthroplasty is more common. Because the most common indication is irreconstructable radial head fracture and degenerative arthritis is not common at the radiocapitellar joint, we think that the osseous anatomy described in young adults will not be different in normal radiocapitellar joints in older patients.

Conclusion

The position of the LARH is found to be perpendicular to the forearm plane when the forearm is in neutral position and perpendicular to the PRUJ plane when the forearm on average in 30° of pronation.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Review and Patient Consent

The ethical committee has reviewed this study and a positive advice was given for this protocol on 15/06/15. Ethics committee UZ Ghent, Chairman: Prof. Dr. Rubens Registration number: B670201420879.

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