ORIGINAL ARTICLE

Humeral Retroversion (Complexity of Assigning Reference Axes in 3D and Its Influence on Measurement): A Technical Note

Fabian van de Bunt[1], Michael L Pearl[2], Arthur van Noort[3]

Abstract

Background: Humeral retroversion (RV) is important to the study of shoulder function and reconstruction. This study tests the hypothesis that clinically obtained computer tomography (CT) measurements for humeral RV (off-axis measurements) differ from those obtained after reformatting the image slice orientation so that the humeral shaft is perpendicular to the gantry (coaxial measurements) and explores deviations from true RV.

Materials and methods: A custom-built application created in Mathematica was used to explore the effect of altering the humeral orientation on slice angle acquisition by 3D imaging technologies, on the perceived angle of RV from the 2D-projection of the reference axes. The application allows for control of humeral axis orientation relative to image slice (3D) or plain of projection (2D) and humeral rotation. The effect of rotating a virtual model of one humerus around its own axis and in discrete anatomical directions on the measured RV angle was assessed.

Results: The coaxial measurement of humeral RV (31.2°) differed from off-axis measurement, with a maximum difference in measured RV of 50° in 45° of extension. The typical position of the humerus in a CT scan resulted in a difference in RV measurement up to 22°. Explorations of deviation led to the following outcomes, as divided by anatomic direction. Extension and abduction led to an underestimation, and flexion and adduction led to an overestimation of the RV-angle.

Conclusion: Measurements must be done consistently about the position and orientation of the humerus. Deviation in the humeral alignment of as little as 10° can distort the measurement of version up to 15°.

Keywords: Computer tomography, Humeral retroversion, Humeral torsion, Humerus, Shoulder, Shoulder arthroplasty.

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Introduction

Humeral retroversion (RV) is of great importance to the study of shoulder function and reconstruction. Assessment of humeral RV has importance in the treatment of many clinical conditions, such as, arthritis, humeral head fractures, brachial plexus birth palsy and shoulder assessments in throwing athletes.[1–6] Re-establishing humeral RV is a necessary goal in total shoulder arthroplasty (TSA) and for the treatment of fractures of the proximal humerus.[7–13]

In the literature, the assessment of RV is performed using various anatomical landmarks for the proximal axes, such as, the articular borders, the greater and less tuberosity and the bicipital groove.[1,4,14] In general, the most commonly used proximal axis is the line perpendicular to the articular borders[4,7,12,15–18] and for the distal axis the transepicondylar line,[4,15,17,18] while assessing RV using computer tomography (CT) or magnetic resonance imaging (MRI) (Fig. 1). In the older literature, version was assessed by 2D X-ray techniques, in which the correct placement of the upper extremity relative to the X-ray beam was essential for version measurements.[16,19] The current imaging techniques of choice for measuring humeral RV are ultrasound or 3D imaging technologies, such as, CT and MRI. However, even studies utilising 3D imaging technologies in a clinical setting are creating off-axis 2D RV angles, unless corrected for the orientation of the humerus.

Angular measurements for clinical purposes with a CT scan have documented deviations due to patient positioning.[20–24] Variability in measurement outcome in humeral RV has been confirmed by two cadaver studies, even to some extent with 3D reformatting software.[25,26] However, these studies only assessed two different positions of the humerus. To explore the effect of alterations of the position of the humerus relative to the gantry on the measured humeral RV-angle, a custom-built application was created in which we systematically replicated alterations in all anatomical directions. We hypothesised that keeping the off-axis position of the humerus under 10° in all anatomic directions would lead to a measurement error <10°.

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Materials and Methods

A dataset of a male right humerus, made available by The Visible Human Project,[27] courtesy of TolTech industries, Aurora, Colorado, was imported into a custom-built application, created in Mathematica (version 8, Champaign, Illinois). The application was developed to explore the effect of altering the humeral position on the projected angle that defines RV. The application allowed for (1) control of the humeral position, (2) for proximal and distal axes selection and (3) humeral rotation (Fig. 2). Furthermore, the application creates three projection views, a (1) axial, (2) anterior–posterior and (3) lateral view. The axial projection demonstrates the axes that determine the RV-angle calculated by the program, shown in degrees. This view is generally used for measuring RV by CT or MRI scan.

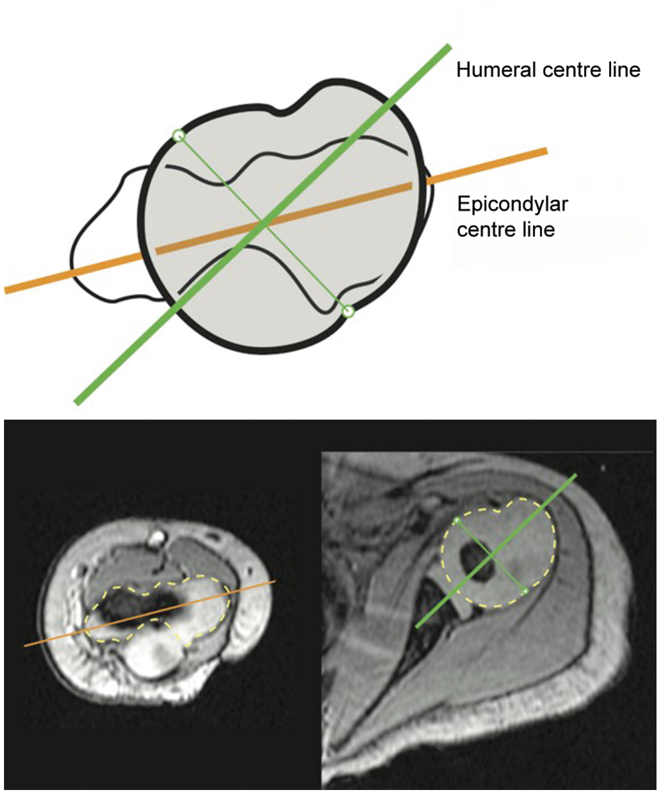


Fig. 1: Retroversion is calculated between the line perpendicular to the articular borders (humeral centre line) and the transepicondylar axis (epicondylar centre line). *Reproduced from*: Pearl ML, Batech M, van de Bunt F. Humeral retroversion in children with shoulder internal rotation contractures secondary to upper-trunk neonatal brachial plexus palsy. J Bone Joint Surg Am 2016; 98: 1988–1995 [PMID: 27926680. DOI: 10.2106/JBJS.15.01132]

We performed our analysis based on the most commonly chosen reference axes in the clinic: the perpendicular line to the line connecting the borders of the articular surface (articular surface orientation) as the proximal axis and the transepicondylar axis as the distal axis. We assessed possible measurement error (ΔRV) relative to the true RV angle by increasing the off-axis position of the humerus in each anatomic direction and later added a rotational component (internal or external rotation of the humerus), measurement outcomes were plotted in various graphs.

First, the influence on the measured RV-angle of each separate anatomical direction (extension, flexion, abduction and adduction) was analyzed, by increasing the off-axis position with steps of 5°, up to 45°.

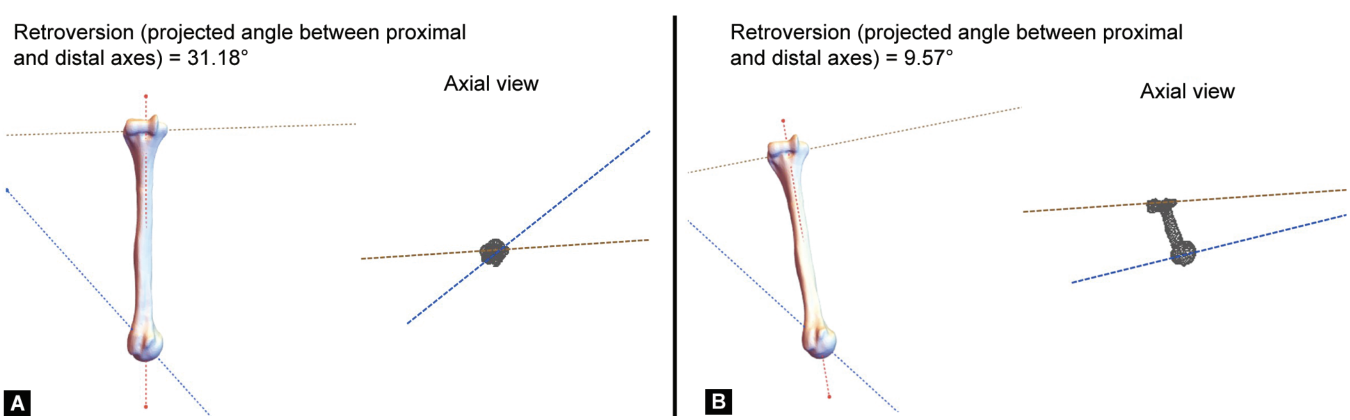
Next, we further analyzed possible measurement error in similar steps, but with combined anatomical directions. These combined directions were flexion/extension with ab/adduction. To these combinations, a rotational component was added. Third and finally, a rotational component was included in a static position of the humerus. To explore the effect of solely adding a rotational component, the humerus was set (1) coaxial, (2) 10° of abduction and (3) in 20° abduction, for these three positions internal and external rotation was added in steps of 10°, up to 50° of rotation. The application measures the version angle from the 2D-projection of the reference axes defined on the 3D model of this humerus.

Results

The coaxial measurement of humeral RV (31.2°) differed from all off-axis RV measurements, with a maximum deviation of 49° in 45° of extension and 58° in adduction (Table 1). The typical position of the humerus while obtaining a CT scan of slight abduction (≈10°) and extension (10°–20°), resulted in a difference in RV measurement as much as 22°.

Rotating the humerus about any axis that is not coaxial with its own axis, altered the projected angle and the measured RV angle.

Extension and abduction led to an underestimation of the true RV-angle, and flexion and adduction led to an overestimation of the true RV-angle (Fig. 3). The anatomical directions which created the



Figs 2A and B: (A) A screenshot of the application. The panel to the left shows a humerus oriented vertically, in a Cartesian coordinate system. The blue line represents the proximal humerus, perpendicular to the base of the articular surface, the brown line represents the distal humerus (the transepicondylar axis), and the red line represents the humeral shaft defining the humeral axis; (B) Screenshot depicting the humerus in an off-axis alignment (20° extension and 10° abduction)

Table 1: Deviations in RV measurement per anatomic direction

Degrees off-axis (°)	*Extension (ΔRV in °)*	*Abduction (ΔRV in °)*	*Flexion (ΔRV in °)*	*Adduction (ΔRV in °)*
5	−4.0	−2.3	3.5	2.7
10	−8.6	−4.1	6.5	6.1
15	−13.6	−5.7	9.2	10.2
20	−19.1	−7.0	11.5	15.2
25	−25.0	−8.0	13.5	21.4
30	−31.2	−8.8	15.1	28.9
35	−37.4	−9.6	16.6	37.6
40	−43.6	−10.2	17.7	47.4
45	−49.4	−10.7	18.7	57.7

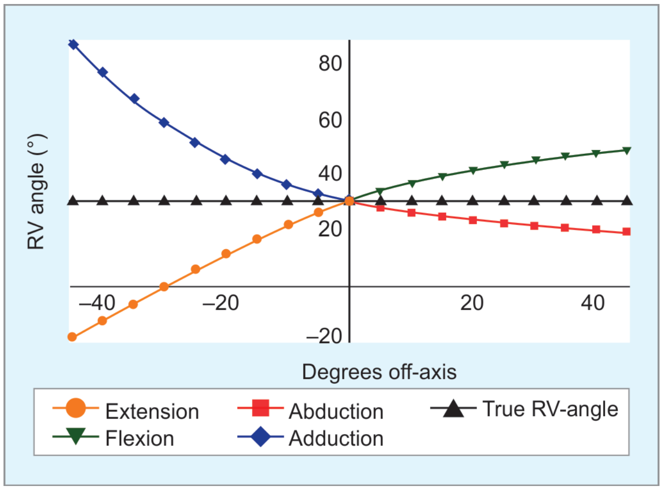


Fig. 3: Effect of flexion/extension and abduction/adduction of the humerus on the projected RV-angle. Each position was increased by increments of 5° plotted relative to the true RV-angle

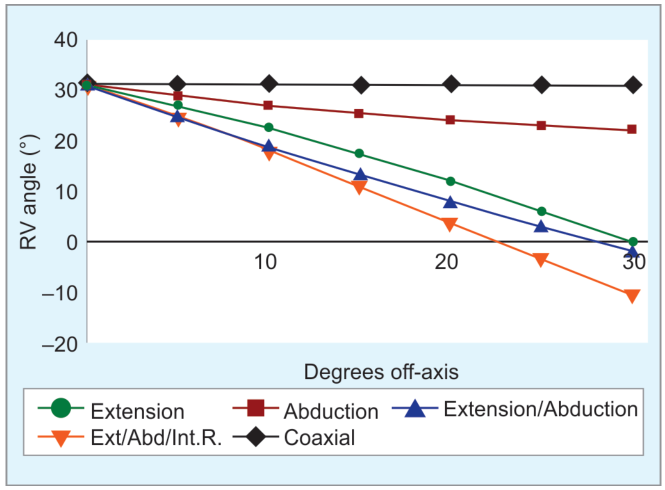


Fig. 4: Effect of additive and combined rotations of extension, abduction, and internal rotation of the humerus on projected RV-angle. Each position was increased by increments of 5° plotted relative to the true RV-angle

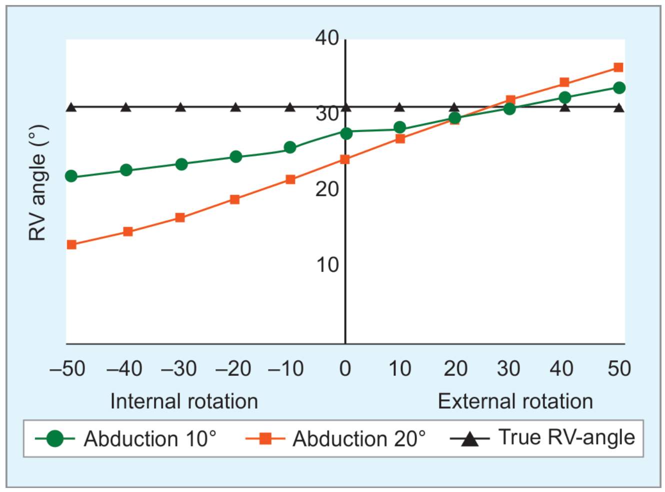


Fig. 5: Effect of internal and external rotation around the axis of the humerus on projected RV-angle in two selected off-axis positions of the humerus: 10° and 20° abduction. The rotation was increased by increments of 10° and outcomes are plotted relative to the true RV-angle

largest measurement deviation were extension and adduction, of which extension is most relevant, since the patient's torso limits the humerus from adducting in a clinical setting.

The overestimation and underestimation directions together increased the deviation from true RV, as shown in Figure 4 for extension and abduction. In this figure, there was also an (internal) rotational component added to these anatomic directions, this increased the amount of deviation.

Rotating the humerus about its own axis when it is not coaxial aligned will also result in variation in the RV-angle measured, as shown in Figure 5. This effect increased along with the off-axis position of the humerus. In off-axis positions, rotation had a direct influence on the measured RV-angle. Rotating the humerus about its own axis could alter the RV-angle as much as 18° when the humerus is positioned off-axis. External rotation "corrects" towards true version and internal rotation increases the deviation when this humerus is in extension and abduction.

Discussion

The measure of humeral RV varies depending on numerous factors, many that have been discussed in the prior literature including but not limited to humeral orientation in the gantry (while using CT or MRI), the level of the image slice and correspondingly slice orientation. The present study highlights the importance of defining all three reference axes from which the RV value is derived, including the less obvious humeral shaft axis that may be implicit in the angle of projection.[3,5,12,26] This study argues the methods that create a 2D-projection of RV, using only a proximal and a distal image slice, must account for any deviation from a coaxial projection after defining the shaft axis of the humerus.

The outcome of humeral RV measurement varies when the humeral axis is not exactly coaxially aligned to the gantry, due to its effect on slice orientation. In our study, RV measurement outcomes are over- or underestimations of true RV depending on the anatomical direction of deviation from coaxial. Furthermore, increased deviation from a coaxial position increased the measurement error. Generally, in a supine position for CT or MRI scanning, the humerus is in slight abduction, extension, and internal rotation, a combination leading to underestimation of the RV angle, this position could quickly generate a measurement error >10°.

The application developed for this study measures the version angle from the 2D-projection of reference axes defined on the 3D model of the humerus. This differs from most reports of clinical measurements, wherein reference axes are assigned to anatomical landmarks depicted on select 2D slices chosen for version measurement.[4,15,17,28] The orientation of these 2D slices often does not have any systematic relation to the humeral shaft axis, depending on the study. In our explorative study, we observed a systematic error in version measurement when the humerus is set off-axis.

In addition, Harrold and Wigderowitz explored yet another factor causing measurement variability while measuring humeral RV from CT or MRI image slices.[12] They studied the effect of the irregular geometry of the articular borders of the humeral head on humeral RV measurements, in humeri without skeletal abnormalities. The RV-angle varies while assigning the proximal axis more superiorly or inferiorly relative to the midpoint of the articular surface. This was illustrated by a mean RV-angle at the midpoint of 18.6°, increasing to 22.5° superiorly, and decreasing inferiorly to 14.3°.

A relationship between changes in RV and clinical outcome of TSA has not been fully established. However, it is clear that alterations in RV alter the center of rotation and shifts the arc of motion, affecting the stability of the joint. Furthermore, the change in a line of force following alteration of the humeral RV-angle will result in eccentric loading on the glenoid, increasing the risk of excessive glenoid wear and glenoid loosening.[3,12] Inadequate RV angles, defined as a deviation >15° from individual version have been reported by several studies in more than 20% of their cases.[29,30] Boileau et al. described this as a mean miscalculation of 11.5° from individual humeral RV in their study.[3] Our study presents a possible cause of these varying deviations.

The outcome of humeral RV measurements depends on multiple factors, resulting in a true RV-angle per individual humerus with regards to the reference axes chosen, the position of the humerus during imaging and the imaging technique used. The axis of the humerus that defines the plane of projection is often implicit in the methodology. Therefore, mean RV-angles will vary across studies in the literature. Future advancements in three-dimensional realignment software will likely decrease this variation. However, the correct use of this kind of software depends on whether one understands and agrees with the assumptions made by the program about reference axis selection. Note also that the amount and location of data points chosen to realign the humerus will vary across software, so there will be outcome variation, but probably well within an error margin of 10°. Our findings show that the customising version is not without deviation either, especially without 3D reformatting tools. Estimating a mean off-axis position, relative to coaxial, of about 15° extension and 15° abduction in a clinical CT/MRI setting, poses a measurement error in this humerus of 18.6° in this individual humerus. To perform reliable measurements of humeral RV, measurements must be done consistently with regards to the position of the humerus and proximal and distal reference axes. Measurements that are not made from the coaxial alignment of the humerus are subject to inconsistencies due to the variability of the humeral position. In the clinic, the humerus' off-axis position is probably between 0° and 25° in extension and a similar amount for abduction, but not necessarily equal. In Figure 3, we implemented these humeral positions step by step, visualising the margin of error while performing RV measurements. To keep the error <15° of true RV, the humerus must be within a range of 10° off-axes in all directions.

Limitations

The most important limitation of our study is that the results are based on one humerus. There is individual variation among humeri, probably slightly affecting the amount of deviation from the true RV angle by off-axis positing. However, our main study aim was to present differences in RV measurement caused by off-axis positioning using clinically relevant reference axes and analyze whether a systematic error was apparent. Therefore, we limited our study to one humerus without skeletal abnormalities.

The measurement outcomes in our application are directly related to the projected view, which is different from measuring RV from 2D-slices in which these lines are separately drawn on 2D images. The deviations from the true version while choosing other reference axes (such as, bicipital groove orientation, or longest diameter through the humeral head) may also affect the magnitude of deviation but does not affect the conclusions that can be drawn from this paper, since deviation will still be systematic depending on shaft orientation. Future studies comparing 3D reformatting protocols with 2D-slice measurements are warranted to provide a more extensive insight into the current measurement error margin. Few studies have explored the value of such clinically accessible 3D reformatting protocols for measuring glenoid version,[31] recently Zale et al. explored the clinical application of such an interdepartmental imaging protocol.[32] These studies show that we can correct for humeral alignment as well and this can help to interpret our humeral version measurements, considering the workup for TSA or treatment of fractures of the proximal humerus.

Conclusion

Unlike we hypothesised, the humerus must be within a range of 10° off-axes in all anatomical directions to keep the measurement error <15° of true RV. The version remains an important two-dimensional representation of the complex three-dimensional shape of the humerus, but our understanding of what constitutes normal and the importance of deviation from normal requires thorough reconsideration. Unfortunately, the coaxial alignment of the humerus is yet inconsistent with clinical reality. We recommend implementing interdepartmental 3D reformatting protocols and, until then, to take into account the position of the humerus while interpreting RV measurements.

Authors' Contributions

Fabian van de Bunt: study design, data collection, analysis and interpretation of data, writing of (the first draft) of the manuscript, critical evaluation of the intelligent content of the final version. Michael L Pearl: study design, analysis and interpretation of data, writing of the manuscript, critical evaluation of the intelligent content of the final version. Arthur van Noort: data analysis and interpretation of data, writing of the manuscript, critical evaluation of the intelligent content of the final version.

Ethics Approval and Consent to Participate

Non-required, the data to perform this study were provided to us by TolTech industries, based on the visible human project, which was performed by the U.S. National Library of Medicine. See the reference in the manuscript.

Consent for Publication

All data generated or analyzed during this study are included in this published article.

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