

Original Article

Correlation between anatomical parameters of intertubercular sulcus and retroversion angle of humeral head

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Received December 10, 2014; Accepted February 6, 2015; Epub April 15, 2015; Published April 30, 2015

Abstract: Objective: To obtain anatomical data on intertubercular sulcus of humerus, evaluate the correlation between intertubercular sulcus and retroversion angle of humeral head, to guide the positioning of torsion angle of prosthesis during total shoulder arthroplasty and provide references for shoulder prosthesis design. Methods: Using a Siemens Ultrahigh speed 64-rows multi-slices spiral CT scanner and 20 dried adult humeral specimens (intact specimen, no fractures or pathological damage), of these, left lateral in 10 cases, right lateral in 10 cases, male or female all inclusive, specimens are all provided by Anatomy Department of Weifang Medical College, scan ranged from the highest point of humeral head to the distal ends of trochlea. And scanned data were subjected to statistical analysis. Results: There is a linear correlation between the distance from intertubercular sulcus to central axis line of humeral head, position angle of intertubercular sulcus and retroversion angle of humeral head at the beginning slice of intertubercular sulcus. There is a linear correlation between position angle of intertubercular sulcus and retroversion angle of humeral head at the slice of surgical neck. Conclusion: There is a linear correlation between position of intertubercular sulcus and retroversion angle of humeral head, in total shoulder arthroplasty, using intertubercular sulcus as anatomical landmark will help to accurately position torsion angle of individualized prosthesis. Position angle of intertubercular sulcus is an objective, flexible positioning indicator.

Keywords: Intertubercular sulcus, position angle of intertubercular sulcus, retroversion angle of humeral head, measurement, correlation

Introduction

Retroversion angle of humeral head (or retrotorsion angle, RA) is an important parameter in total shoulder arthroplasty [1-5] and is one of these important reference factors which can influence the outcomes of total shoulder arthroplasty [6-10], and its detailed definition is given below: the plane defined by long axis of humerus and central axis line of humeral head is plane A (Coronal plane of humeral head), and the plane defined by long axis of humerus and the axis lines of distal internal and external humeral epicondyles or the axis line of trochlea is plane B (Coronal plane of humeral condyle or trochlea), and the angle between the two planes is retroversion angle of humeral head. The retroversion angle of humeral head is highly variable among individuals (-8° to $+74^{\circ}$), and there has been many controversies on how to

determine retroversion angle of humeral head during total shoulder arthroplasty [11-16], the correlation between position of intertubercular sulcus and torsion angles and the scientificness and rationality of determining torsion angles using intertubercular sulcus as anatomical landmark. In this study, we had evaluated the correlation between retroversion angle of humeral head and position of intertubercular sulcus and the reliability of determining torsion angles relying on positions of intertubercular sulcus during total shoulder arthroplasty.

Materials and methods

Materials

20 dried adult humeral specimens (intact specimen, no fractures and pathological damage), of these, left lateral in 10 cases, right lateral in 10 cases, male or female all inclusive, specimens

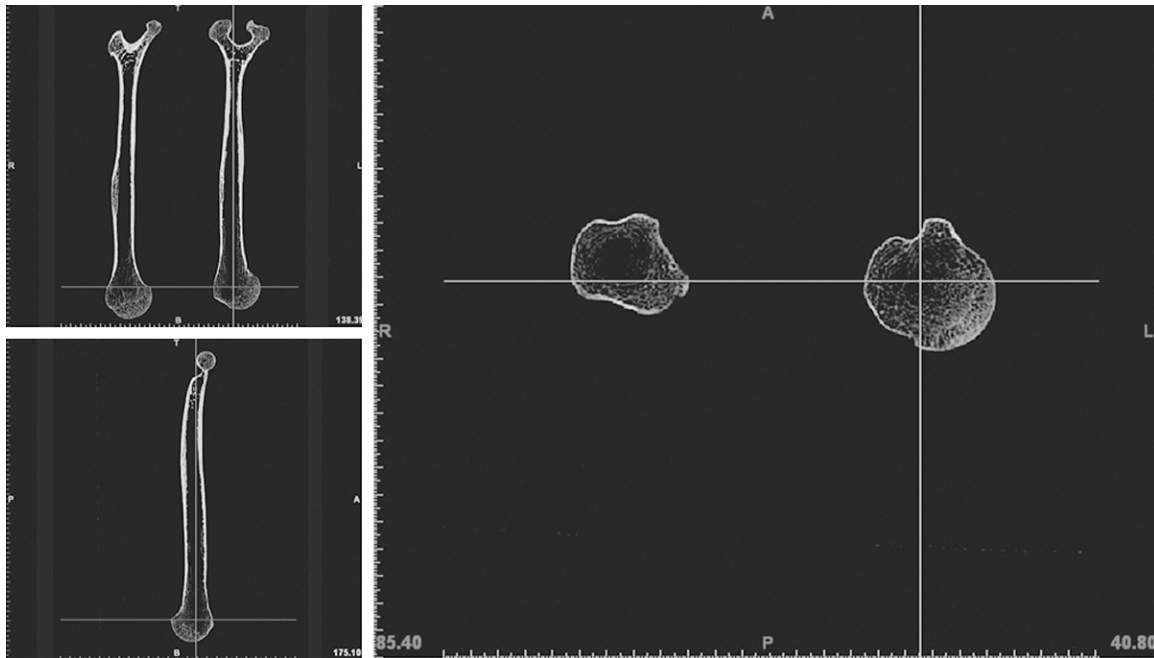


Figure 1. Establish the central axis line of proximal humerus and the central axis point of medullary cavity.

are all provide by Anatomy Department of Weifang Medical College, the experiment has been approved by Weifang City Ethics Association.

Data collection

Using a Siemens Ultrahigh speed 64- rows multi-slices spiral CT scanner, scanning parameter 120 kV, effective 120 mAs-150 mAs, collimator width 1.5 mm, collection slice thickness 5 mm, continuous scanning data collection, overlapping 0.75 mm reconstruction, reconstruction layer thickness 2 mm. Place specimens on pre-customized plastic foams, keeping horizontal, place 2 samples each times, right and left humerus placement taking the head first- supine position, the longitudinal axis of the humerus was parallel to the long axis of examination bed, the scanning range from the highest point of humeral head to the distal end of trochlea. The obtained image data was numbered and transformed into computer.

Measuring the vertical distance from intertubercular sulcus to central axis line of humeral head and the position angle of intertubercular sulcus

Open image data using mimics 8.11 image processing software, at first to determine the axis

line of proximal humeral medullary cavity (**Figure 1**): In coronal plane or sagittal plane windows, select the plane with the largest diameter of proximal humeral medullary cavity, using built-in drawing tools of the software to draw a connection line at the midpoint of proximal humerus 1/3 medullary cavity, which is the axis line of proximal humeral medullary cavity, the axis point of proximal humeral medullary cavity in horizontal plane was denoted as point of O.

Then select three different slices in proximal humerus (shown in **Figures 2-4**), the first slice was at the beginning of intertubercular sulcus, the second slice was the slice with the largest diameter of humeral head, the third slice was at the surgical neck of the humerus; In the first place we had identified the edges of articular surfaces of bilateral humeral heads in the slice with the largest diameter of humeral head and drew a connection line of AB, which was the diameter of humeral head; then drew a perpendicular bisector CD at straight line AB, the straight line CD can be considered as the central axis line of humeral head and straight line CD approximately goes through point O (actually the line CD may be located somewhat behind of point O due to the effects of the eccentricity of humeral head). We then measured the angles between straight line CD and horizontal

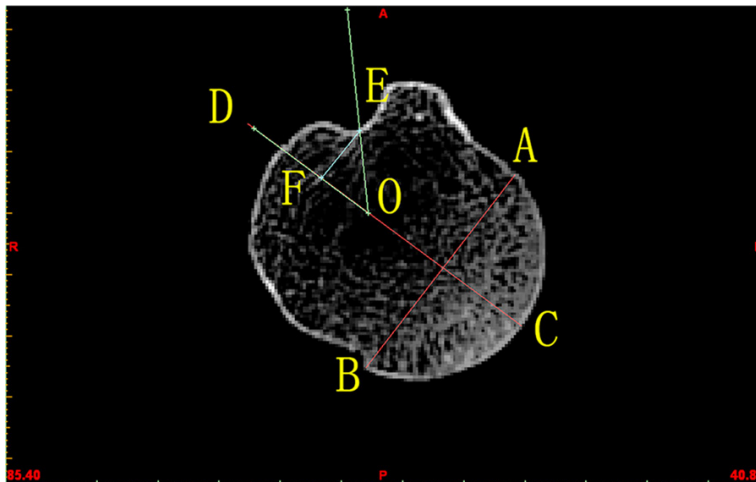


Figure 2. Slice with the largest diameter of humeral head, Straight line AB was the diameter of humeral head, Straight line CD was the central axis line of humeral head, $\angle EOD$ was the position angle of intertubercular sulcus PA, the distance between point E and F was the distance from intertubercular sulcus to axis line of humeral head.

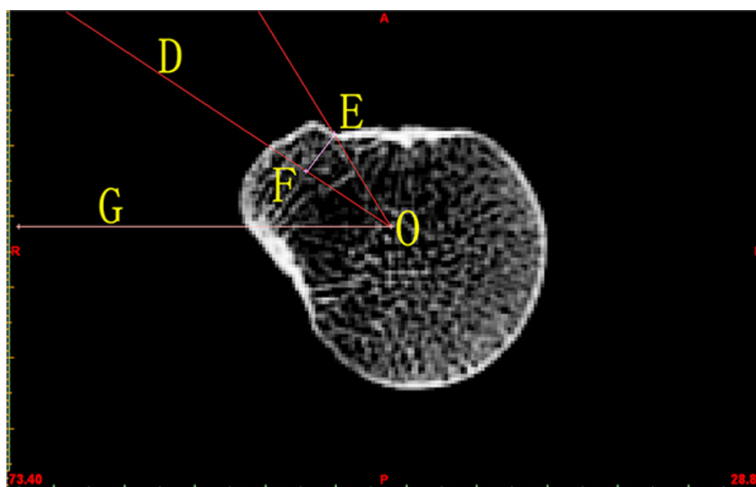


Figure 3. Measurement on the beginning slice of intertubercular sulcus.

line with the built-in angle measurement tool of the software and recorded the measurement data. On this basis, we had drawn the central axis line CDs through the point O at the beginning slice of intertubercular sulcus and slice of surgical neck of humerus, respectively, then at each slice, drew a straight line EO between midpoint E and O, and the angle between straight line CD and straight line EO was the angle between intertubercular sulcus and the central axis line of humeral head, which we called the 'position angle of intertubercular sulcus' (PA: Position Angle). Drew a perpendicular line EF through the lowest point E of intertubercular sulcus against the central axis line of humeral

head (i.e. the straight line CD), which was the perpendicular distance from intertubercular sulcus to the central axis line of humeral head (i.e., distance D). Finally, using the built-in measurement tools of the soft to measure distance D and angle PA.

Measurement on retroversion angle of humeral head (e.g. shown in Figures 5 and 6)

Selected a slice with the largest diameter of humeral head in the horizontal plane window, drew a connection line AB between the edges of the bilateral articular surface of humeral heads, then drew a perpendicular bisector CD against AB, which was the central axis line of humeral head, made measurement on angles between CD and horizontal line with the built-in angle measurement tools of the soft and denoted by α . Then in the distal end of humerus, select a slice with the most prominent internal and external humeral epicondyles and drew a connection line EF between tops of internal and external humeral epicondyles, measured the angle between connection line EF and horizontal line and denoted by β . The angle $\alpha-\beta$ was the retroversion angle of humeral head.

Statistical analysis

We had performed statistical analysis on the obtained data with the Statistics 17.0 package and analyzed the correlation between distance D data from three different slices of the proximal humerus, position angle of intertubercular sulcus (PA) and retroversion angle of humeral head, and to verify if the difference(s) had any statistical significance, $P < 0.05$ as difference with statistical significance.

Results

The measured value of retroversion angle of humeral head was $32.10^\circ \pm 14.10^\circ$ (0.43° -

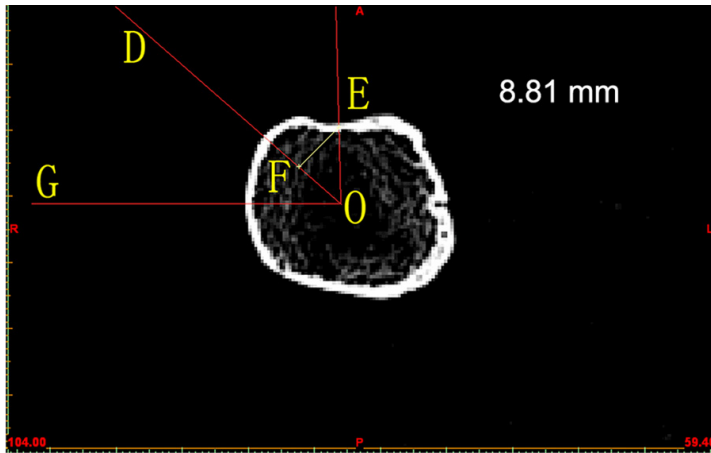


Figure 4. Measurement on slice of surgical neck of the humerus.

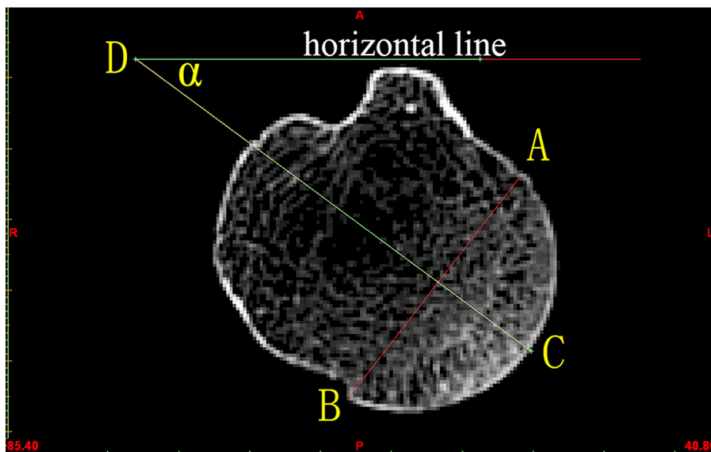


Figure 5. Line CD was the central axis line of humeral head, α was the angel between line CD and horizontal line.

54.69°), specifically, the right value was $31.76^\circ \pm 14.80^\circ$ and the left value was $31.47^\circ \pm 15.22^\circ$, we had performed single-factor analysis of variance on the obtained values of bilateral torsion angles, with the results of $F = 0.002$, $P = 0.966$, which was greater than 0.05, thus, it is considered that there was no significant difference between the left and right lateral of the retroversion angle of humeral head in the same individual (Table 1).

In beginning slice of intertubercular sulcus: the distance D form intertubercular sulcus to central axis line of humeral head was 7.71 ± 2.44 mm, and the correlation coefficient between distance D and retroversion angle of humeral head was -0.569, the significance test (on both sides) showed $P = 0.009$, which was less than 0.01, reached significant level, thus, it can be

considered there is a linear correlation between the distance from intertubercular sulcus to central axis line of humeral head (distance D) and retroversion angle of humeral head at the beginning slice of intertubercular sulcus. The position angle of intertubercular sulcus was $35.09^\circ \pm 10.78^\circ$, the correlation coefficient between position angle of intertubercular sulcus and retroversion angle of humeral head was -0.488, significance test (on both sides) showed $P = 0.029$, which was less than 0.05, reached significant level, and then, we might also think there is a linear correlation between the beginning slice of intertubercular sulcus and retroversion angle of humeral head.

At the slice with the maximum diameter of humeral head, the distance from intertubercular sulcus to central axis line of humeral head (distance D) was 9.06 ± 2.51 mm, and the correlation coefficient between distance D and retroversion angle of humeral head was -0.351, significance test (on both sides) showed $P = 0.130$, which was greater than 0.05, not reaching significant level, thus, we considered that there is no correlation between the distance from intertubercular

sulcus to central axis line of humeral head and retroversion angle of humeral head at the slice with the maximum diameter of humeral head. Position angle of intertubercular sulcus was $36.48^\circ \pm 9.44^\circ$, and the correlation coefficient between position angle of intertubercular sulcus and retroversion angle of humeral head was -0.317, significance test (on both sides) showed $P = 0.173$, which was greater than 0.05, also not reaching significant level, thus, we considered that there is no correlation between position angle of intertubercular sulcus and retroversion angle of humeral head at this slice.

In the slice of surgical neck, the distance from intertubercular sulcus to the central axis line of humeral head (distance D) was 7.30 ± 1.63 mm, and the correlation coefficient between

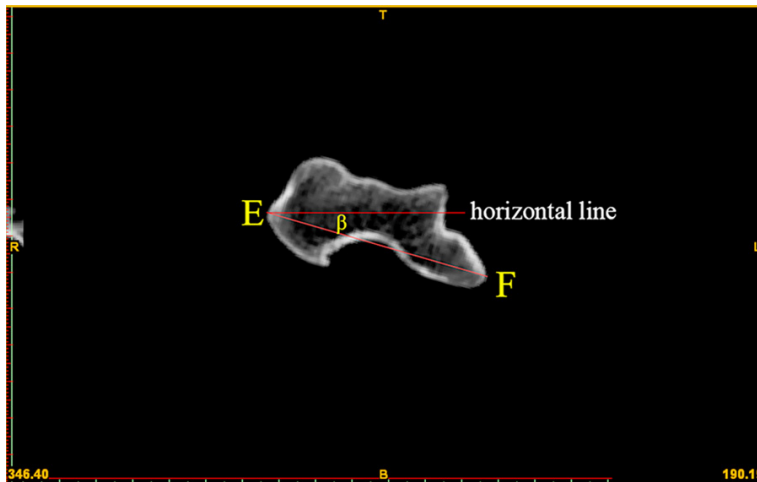


Figure 6. Line EF was the connection line between internal and external humeral epicondyles, β was the angle between line EF and horizontal line, α and β were retroversion angle of humeral head.

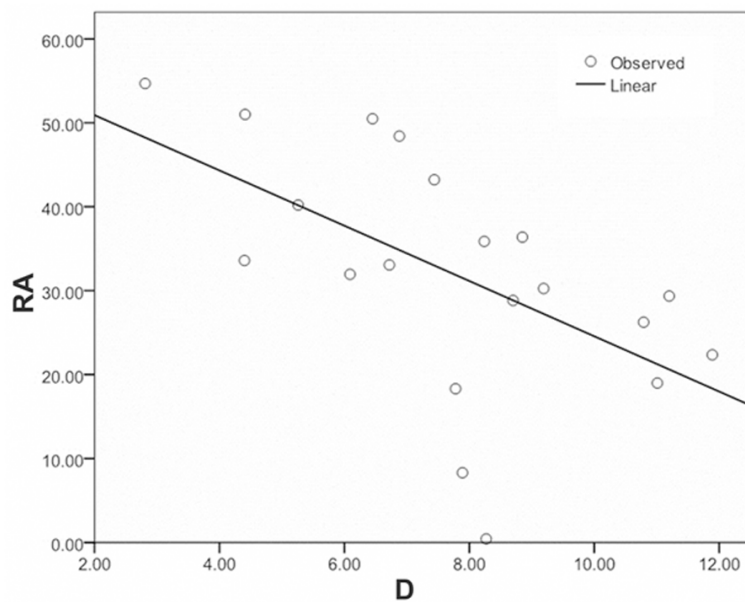


Figure 7. Correlation analysis performed on the distance from intertubercular sulcus to central axis line of humeral head (distance D) and retroversion angle of humeral head (RA) at the first slice. X-axis was D, Y-axis was RA.

distance D and retroversion angle of humeral head was -0.428 , significance test (on both sides) showed $P = 0.06$, which was greater than 0.05 , not reaching significant level, thus, we considered that there is no correlation between the distance from intertubercular sulcus to the central axis line of humeral head and retroversion angle of humeral head at the slice of surgical neck.

and placing a prosthesis of head of humerus. However, it has been confirmed in anatomical studies that there is considerable variation in retroversion angle of humeral head in the general population [17], thus, there has been considerable controversies in the scientific of using an identical posterior inclination angle to handle the significant heterogeneity in posterior inclination angles of humeral head among indi-

Position angle of intertubercular sulcus was $39.78^\circ \pm 8.55^\circ$, and the correlation coefficient between position angle of intertubercular sulcus and retroversion angle of humeral head was -0.494 , significance test (on both sides) showed $P = 0.027$, which was less than 0.05 , reached significant level, thus, we considered that there is a correlation between position angle of intertubercular sulcus and retroversion angle of humeral head at this slice (shown in **Tables 2, 3**).

Finally, we had performed regression analysis on the above data (**Figures 7-9**), results showed that in beginning slice of intertubercular sulcus, retroversion angle of humeral head = $57.503 - 3.293 \times$ the distance from intertubercular sulcus to central axis line of humeral head; retroversion angle of humeral head = $54.499 - 0.638 \times$ Position angle of intertubercular sulcus; in slice of surgical neck, retroversion angle of humeral head = $64.501 - 0.814 \times$ Position angle of intertubercular sulcus.

Discussion

Currently, there are many monographs on total shoulder arthroplasty in which the authors all recommended the maintenance of a posterior inclination angle varying from 30° to 40° or from 20° to 35° when performing an osteotomy

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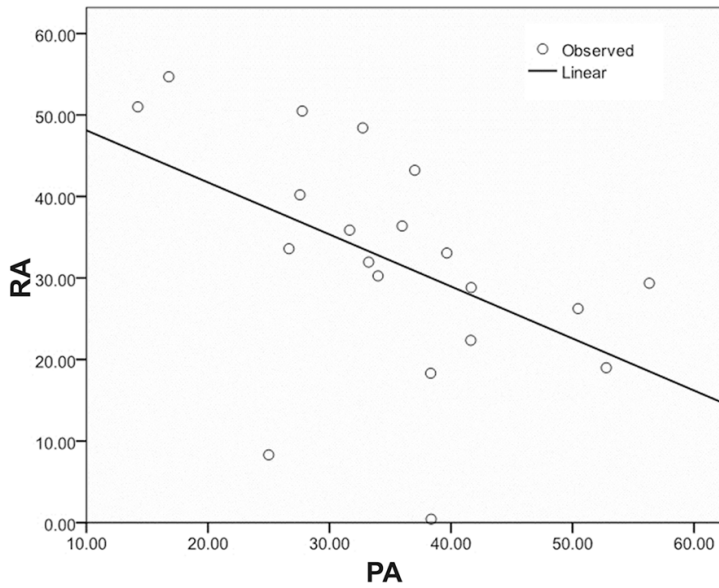


Figure 8. Correlation analysis performed on the position angle of intertubercular sulcus (PA) and retroversion angle of humeral head (RA) at the first slice. X-axis was PA, Y-axis was humeral head RA.

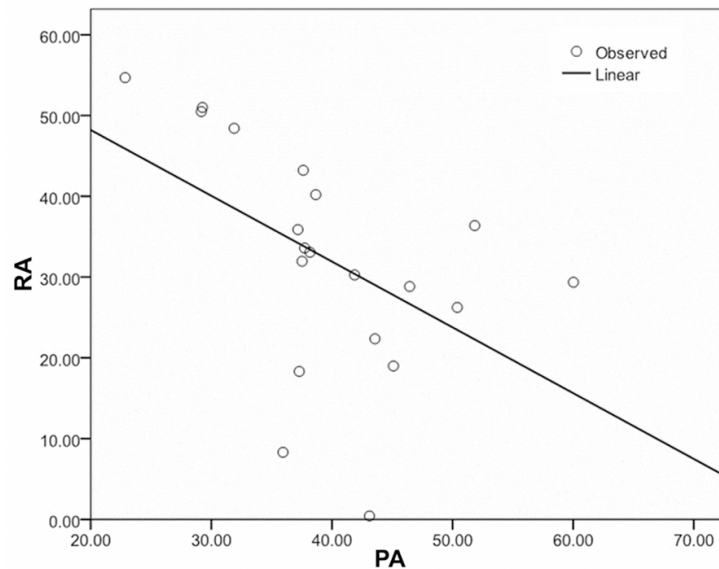


Figure 9. Correlation analysis performed on the position angle of intertubercular sulcus (PA) and retroversion angle of humeral head (RA) at third slice. X-axis was PA, Y-axis was humeral head RA.

viduals. In recent years, some researchers found in clinical studies that the gaps between conventional prosthesis placement angles and individual anatomical parameters will often result in the destruction of the soft tissue balance in shoulder joint and cause a series of serious complications such as anterior & poste-

rior shoulder instability, strike and dislocation, which will eventually lead to asymmetry abrasion in glenoid cavity and prosthesis loose, the direct consequences of these problems include but not limited to the failure of total shoulder arthroplasty and the performance of an revision surgery.

In 1998, Anthony j. Doyle and others had performed a MRI survey on 41 volunteers and 9 corpses, the study revealed a linear correlation between the distance from intertubercular sulcus to central axis line and retroversion angle of humeral head, based on these observations he believed that it was more reliable for surgeons to determine the positions of the shoulder joint prosthesis placement in reference to the position of intertubercular sulcus than to the rather unrealistic hypothesis of the existence of an identical torsion angle [18]. In the same year, Frederick J. Kummer and his colleagues had performed a series of measurements on 420 humerus by means of a self-made instrument with a protractor, the authors found that, due to the highly variable values of intertubercular sulcus and retroversion angle of humeral head, the approach of using intertubercular sulcus as a reference mark in determining the positions of prosthesis may produce an error of 10° or even larger errors in some specific patients [17].

Others had established that the distance from intertubercular sulcus to the central axis line was $11.8 \text{ mm} \pm 2.35 \text{ mm}$ and the authors believed placing the lateral dorsal of prosthesis at a position 12 mm behind intertubercular sulcus could help to resume the preoperative normal retroversion angle of humeral head [18]. In 2001, Axel Hempfing and others had performed high-resolution CT scans on 50 humerus, four

levels were equally divided between the beginning level of joint edges intertubercular sulcus and the level 5 cm below, and to measure the distance from intertubercular sulcus to equatorial plane (axial plane) of humeral head on each level sequentially, and the measured distances of four levels from top to bottom were 8.0 ± 1.4 mm, 10.2 ± 1.4 mm, 10.1 ± 1.3 mm and 8.5 ± 1.1 mm, respectively, the values from the four groups followed the Gaussian distribution, and the differences between proximal end and distal end had no statistical significance [19]. The above data are mostly collected from samples from Caucasian population, while the specimen data collected from Asian population in our study indicated that the average distance from intertubercular sulcus to the axis line of the humeral head was 7.71 ± 2.44 mm, which was significantly shorter and more variable than the above data of corresponding levels. The results of the study also established that the value of retroversion angle of humeral head in Asian population was $32.10^\circ \pm 14.10^\circ$ (0.43° - 54.69°) with a more apparent inter-individual variability.

Thus, given the characteristics of shorter and highly variable distances from intertubercular sulcus to the axis line of humeral head and the more variable retroversion angle of humeral head in Asian population [20], the surgeries performed using the data obtained from previous studies as guidelines will inevitably make the posterior inclination angles of prosthesis too larger, which will in turn create difficulties for surgery to achieve satisfactory results and even lead to surgical failure. In this study, samples were taken from Asian population and thus, the obtained data was more in line with the anatomical characteristics of Asian populations, and the total shoulder arthroplasty performed on Chinese patients using these data as guideline can effectively reduce the errors of torsion angles.

For the first time, we found from measurements that there was a significant linear correlation between the position angles of intertubercular sulcus and retroversion angles of humeral head at the beginning level of intertubercular sulcus, which suggested the possibility that the position angles of intertubercular sulcus might be used as an important auxiliary parameter in the selection for shoulder prosthesis placement angles. In total shoulder arthroplasty, surgeons

can place the lateral dorsal of prosthesis in a distance from the beginning of intertubercular sulcus (7.71 ± 2.44 mm) in reference to the distance from intertubercular sulcus to the axis line of humeral head, and maintain an angle between the lateral dorsal of prosthesis and intertubercular sulcus ($35.09^\circ \pm 10.78^\circ$) based on the measurement data of position angle of intertubercular sulcus during prosthesis placement to further improve the accuracy and reliability of prosthesis placement angle and resume the preoperative retroversion angle of humeral head of every patients more efficiently.

Based on the difference in correlation coefficient between the position angles of intertubercular sulcus and retroversion angles of humeral head at different levels, we found the beginning of intertubercular sulcus as the most reliable reference mark, which was followed by surgical neck of intertubercular sulcus. These findings suggested that in total shoulder arthroplasty, in addition to the entry of intertubercular sulcus, the surgical neck of humerus can also be used as a reference mark in positioning. In the cases of proximal humerus comminuted fractures, the beginning of intertubercular sulcus and the surrounding region often can not achieve anatomic reduction and thus lose the significance as a positioning mark, besides, the distance from intertubercular sulcus to the central axis line of humeral head can not be used as a reference. Then using the intertubercular sulcus at surgical neck level as a reference mark in combination with position angle of intertubercular sulcus, the placement angle of prosthesis can also be accurately determined.

The fact of correlation between position angle of intertubercular sulcus and the retroversion angle of humeral head also promoted an idea that in prosthesis design a forward dorsal should be located in front of the lateral dorsal and can form an angle of $35.09^\circ \pm 10.78^\circ$ with it, and surgeons can take the forward dorsal in alignment with the beginning of intertubercular sulcus, which will guarantee the achievement of a torsion angle of $32.10^\circ \pm 14.10^\circ$. In addition, the conclusions of this study can also be used to guide individualized total shoulder arthroplasty: This study had demonstrated that the left and right lateral retroversion angles of humeral head in the same individual had no statistically significant difference, so we can

perform the individualized preoperative measurements on patient's contralateral humeral head anatomical parameters to guide surgeon to place prosthesis precisely in the normal anatomic position.

The limitations of this study include: Firstly, due to the limited sources of donors, the smaller sample size in this study may lead to individual results deviations from the overall mean results; Secondly, in this experiment we had ignored the eccentricity of humeral head and taken the assumption of the central axis line of humeral head approximately going through the axis line of proximal humeral medullary cavity to simulate the actual humerus prosthesis placements in surgical process (the details of surgical procedure refer to "Campbell Orthopedic Surgeons"), which may cause some deviations of experimental data from the normal anatomy measurements, however, since most prosthesis designs and operating specifications are based on the assumption of the central axis line of humeral head approximately going through the axis line of proximal humeral medullary cavity, the conclusions drawn from this study was more closer to the actual surgical operation and had more practical significances. Given the above limitations, we will continue in subsequent experiments to refine and improve experiment designs.

Acknowledgements

This study was supported by Study on epidemiology and clinical intervention of shoulder injury in the overhead sports of Modern military training (CJN13J004).

Disclosure of conflict of interest

None.

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