# Three-Dimensional Morphometric Study of the Thai Proximal Humerus: Cadaveric Study

Panya Aroonjarattham D Eng*, Pongnarin Jiamwatthanachai M Eng*,
Banchong Mahaisavariya MD**, Thanya Kiatiwat PhD*,
Kitti Aroonjarattham MD***, Kriskrai Sitthiseripratip D Eng****

** Faculty of Engineering, Kasetsart University, Bangkok, Thailand*
*** Faculty of Medicine, Siriraj Hospital, Mahidol University, Bangkok, Thailand*
**** Faculty of Medicine, Ramathibodi Hospital, Mahidol University, Bangkok, Thailand*
***** National Metal and Materials Technology Center, Pathumthani, Thailand*

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*Seventy-six cadaveric humeri were investigated to study the three-dimensional morphometric data based on CT data. The present study was an advanced method to determine the 3D proximal humeral parameters for both intra and extra geometries through the utilization of medical imaging and reverse engineering techniques. The following parameters were calculated for each humerus and then compared with the 3D Caucasian data such as diameter of humeral head, articular surface thickness, inclination angle, retroversion angle, medial offset, posterior offset, curve length, radius of curvature, and mediolateral angle. It was found that the Thai humeral parameters were smaller than Caucasian except the retroversion angle and posterior offset. This data could be further used to develop a proper design of shoulder arthroplasty for Thai patients.*

**Keywords:** *Cadaver, Morphometric, Proximal humerus, Three-dimensional model*

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The variation in geometrical data on the proximal humerus shows that the Thai humerus is relatively different from the Caucasian. A previous study reported that small changes in anatomy might have important biomechanical consequences(1). Therefore, there is some likelihood that using a shoulder arthroplasty that is based on the Caucasian design in the Thai patient may not achieve the optimal clinical outcomes. Prosthetic arthroplasty of the shoulder is widely practiced for the treatment of glenohumeral arthritis (such as osteoarthritis, traumatic arthritis, osteonecrosis, rheumatoid arthritis, and cuff tear arthroplasty). It has been reported that 0.5-2% of primary shoulder prosthesis will be complicated by a post-operative periprosthetic fracture(2,3). The aim of shoulder prosthesis replacement is to restore normal kinematics with anatomic location and orientation of the humeral and glenoid joint surfaces. Correcting soft tissue tensioning and muscle tendon balancing by accurate reconstruction of the normal anatomy will optimize the outcome of total shoulder arthroplasty(4,5). In the design of prosthetic replacements for the proximal part of the humerus, the importance of accuracy in the normal three-dimensional anatomy must be emphasized, as shown in Fig. 1 when high shoulder prosthesis is used in the humeral bone.

The present study was aimed at evaluating morphometric data on the Thai proximal humerus both intra- and extra-medullary. It uses the data obtained from computed tomography (CT). Advanced medical imaging and reverse engineering techniques were used to derive the internal geometry without destruction of the specimens.

## Material and Method

### *Three-dimensional modeling*

Seventy-six Thai cadaveric humeri (38 rights and 38 lefts) from the Department of Anatomy, Faculty of Medicine, Siriraj Hospital were used in this study.

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*Correspondence to: Sitthiseripratip K, National Metal and Materials Technology Center (MTEC), 114 Thailand Science Park, Paholyothin rd., Klong 1, Klong Luang, Pathumthani 12120, Thailand. Phone: 0-2564-6500 Ext. 4021, 4022, 4378, Fax: 0-2564-6373. E-mail: kriskrs@mtec.or.th*

The donors were 18 males, 15 females, and five individuals of unknown sex; they ranged in age at the time of death from 22 to 79 years (average, 47.71). The humeri were scanned with a GE Light Speed Pro Series computerized tomographic (CT) scanner. None of the donors had had any surgical procedure performed on the humeri.

Twelve humeri at a time were placed into an acrylic box as shown in Fig. 2 and scanned. CT sections were available for the humeri with a spacing of 0.625-mm slice thickness. The inner and outer contours were identified by different thresholding methods from the CT images. The CT data were transferred to medical image processing software (Mimic, Materialise N.V., Belgium) and then exported as stereolithography (STL) files.

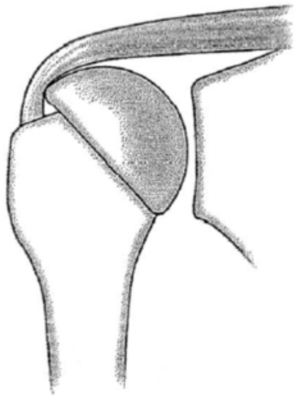

**Fig. 1** This shoulder prosthesis is too high, so the head rubs against the supraspinatus(6)

**Fig. 2** A set of twelve humeri in the CT scanner

Each humeral model, STL file, was imported into reverse engineering CAD software and displayed as a point cloud. The shape of each specific portion of the humerus was approximated with a simple geometric configuration, such as a circle, an ellipse, or a sphere, that best fit the real geometry.

The *fit sphere* function, which is the optimal least squares spherical approximation to a three-dimensional point cloud, was applied to derive the geometric data of the humeral head. The *fit cylinder* function, which is the optimal least squares cylindrical approximation to a three-dimensional point cloud, was applied to derive the straight portion of the intramedullary canal of the proximal humerus. The *fit circle* function, which is the optimal least squares circular approximation to two-dimensional point cloud, was applied in the humeral shaft region. The details of each step are summarized below:

a) The first step was to determine the *"anatomical neck plane"*, which was the best plane fit to the periphery of the articular surface as shown in Fig. 3.

b) The second step was to determine the sphere that best fit the humeral head; this is called the *"epiphyseal sphere"* and is shown in Fig. 3. The humeral head diameter, the center of rotation, and the humeral head axis, which was the perpendicular distance from the anatomical neck plane to the periphery of the epiphyseal sphere were derived, and the intersection area of the anatomical neck plane and epiphyseal sphere gave the *"diameter of articular surface"* and the *"articular surface thickness"*.

c) The third step was to determine the cylinder that best fit the upper intramedullary canal, which is called the *"metaphyseal cylinder"*. This cylinder was limited to the proximal half of the bone because there is a change in curvature in the coronal plane. It extended from 16% to 43% of the length of the humerus, from the tip of humerus as shown in Fig. 3. From the canal axis and the anatomical neck plane axis, the *"inclination angle"*, the *"mediolateral angle"*, the *"medial and posterior offset"* was derived.

d) The fourth step was to determine the cross sections of the intramedullary canal; fit circles were used to fit each section. From the centers of all sections, the *"curve length"* and the *"radius of curvature"* were derived.

e) The final step was to create a line at the distal part of the humerus from the medial epicondyle to the lateral epicondyle, called the *"transepicondylar axis"* and another line at the distal part of humerus from the capitulum to the trochlea, called the "*tangent elbow axis"*. From these, the "*retroversion angles"* were derived.

***Measurements of the proximal humerus***

After geometric simplification of the CAD models of the humerus, the dimensions of each studied parameter were measured in three-dimensions. The 11 morphometric parameters of the humerus(7) were measured as follows:

a) The Diameter of the Humeral Head as shown in Fig. 3 was the diameter of the epiphyseal sphere. This also determined the center of rotation.

b) The Diameter of the Articular Surface as shown in Fig. 3 was the diameter of the circle on the anatomical neck plane. This circle was the intersection of the epiphyseal sphere with the anatomical neck plane.

c) The Articular Surface Thickness as shown in Fig. 4 was the perpendicular distance from the center of the circle of the anatomical neck plane to the apex of the epiphyseal sphere. This thickness represented the distance of insertion of the humeral head into the rotator cuff.

d) The Inclination Angle as shown in Fig. 4 was the angle between the metaphyseal cylinder axis and the humeral head axis.

e) The Retroversion Angle (Transepicondylar; B1), shown in Fig. 5, was the angle between the humeral head axis and the transepicondylar axis.

f) The Retroversion Angle (Tangent Elbow: B2), shown in Fig. 5, was the angle between the humeral head axis and the tangent elbow axis.

g) The Medial Offset, shown in Fig. 6, was the perpendicular distance on the axial plane between the center of the epiphyseal sphere and the central axis of the metaphyseal cylinder.

h) The Posterior Offset, shown in Fig. 6, was the perpendicular distance on the coronal plane between the center of the epiphyseal sphere and the central axis of the metaphyseal cylinder.

i) The Curve Length, shown in Fig. 7, was the length of the intramedullary canal axis.

j) The Radius of Curvature was the radius of the curve length.

k) The Mediolateral Angle, as shown in Fig. 8, was the angle between the entry point and the

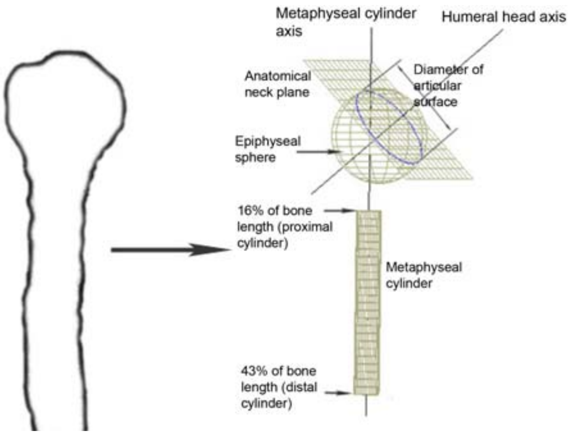

**Fig. 3** Cloud point of the humerus approximated with simple geometric shapes

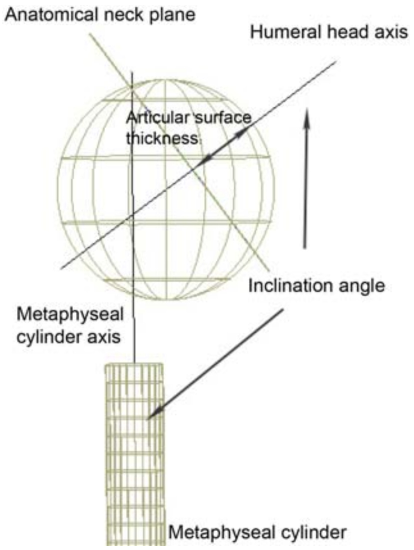

**Fig. 4** The articular surface thickness and the inclination angle were measured with simple geometric shapes

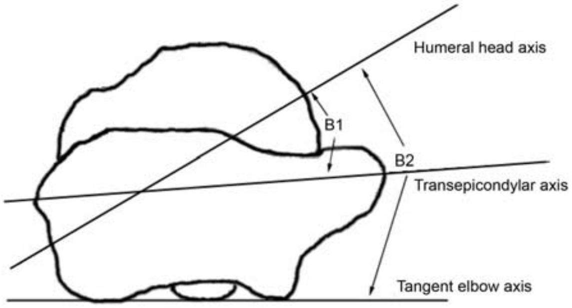

**Fig. 5** The retroversion angles at the distal humerus

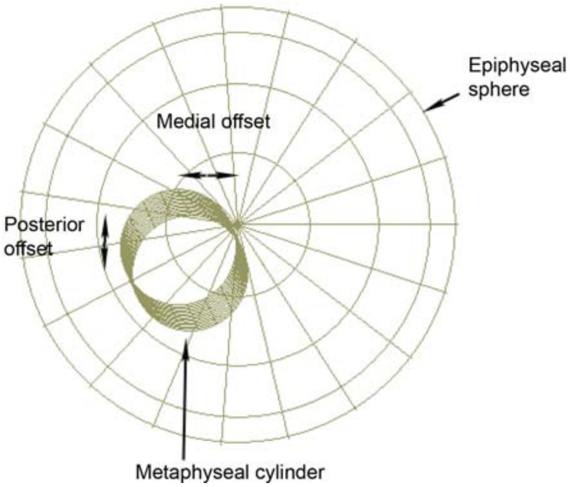

**Fig. 6** Medial and posterior offset of the humerus

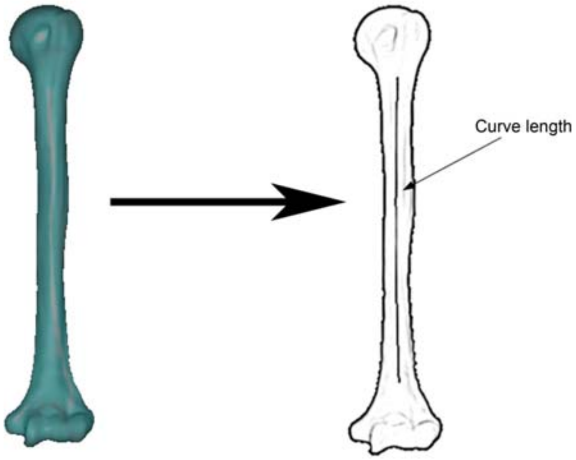

**Fig. 7** The curve length of the intramedullary canal

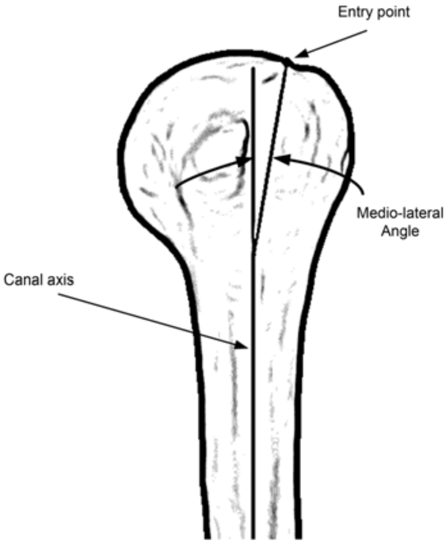

**Fig. 8** The mediolateral angle was measured from the entry point

metaphyseal cylinder axis(8), the entry point being the point on the top margin of the anatomical neck of the humeral head, medial to the greater tuberosity, which is the best point for antegrade nail insertion. Descriptive statistics were used to summarize the results.

## Results

All parameters obtained from the three-dimensional data on the 76 Thai humeri are shown in Table 1 and are compared with data on 65 and 60 Caucasian humeri in Table 2.

The results showed that most parameters of the Thai proximal humerus were smaller than those of the Caucasian; the exceptions were the retroversion angle and posterior offset. The retroversion angles of the Thai population were 31.01° and 33.89° and the posterior offset was 3.37 mm, but the retroversion angles of the Caucasian population were 17.90° and 21.50° and the posterior offset was 2.60 mm. This shows that the Thai humeral head is more inclined to the medio-posterior than the Caucasian and humeral head position tends to the posterior more than the Caucasian.

## Discussion

Determination of humeral bone parameters has been investigated by several researchers with various measurement techniques. The first is direct bone measurement, in which the parameters of cadaveric humeri were measured directly(10-15). The second technique is indirect bone measurements, which have mostly been based on two-dimensional standard radiographic images(2,5,16-19), magnetic resonance imaging (MRI)(19), and computerized tomography (CT)(4,20,21). Some researchers have shown interest in three-dimensional measurements using a stylus probe that can measure and evaluate three-dimensional morphometric data of the outer geometry of the humerus or other long bones(22). The last is an advanced technique, in which long bones were measured based on three-dimensional measurements(7,9,23,24); this gave more accuracy than other methods.

**Table 1.** Morphometric data of the Thai humerus for each parameter (n = 76)

| Parameters | Mean | STDEV | Max | Min | 95% confidence interval |
|---|---|---|---|---|---|
| Diameter of humeral head (mm) | 42.65 | 4.21 | 50.60 | 32.00 | 41.70-43.60 |
| Diameter of articular surface (mm) | 40.51 | 3.88 | 47.60 | 31.00 | 39.64-41.38 |
| Articular surface thickness (mm) | 14.84 | 1.86 | 19.12 | 11.05 | 14.42-15.26 |
| Inclination angle (degree) | 127.64 | 4.28 | 136.00 | 120.20 | 126.68-128.60 |
| Retroversion angle (degree: B1) | 31.01 | 9.72 | 55.60 | 8.14 | 28.82-33.20 |
| Retroversion angle (degree: B2) | 33.89 | 9.71 | 57.00 | 11.90 | 31.71-36.07 |
| Medial offset (mm) | 5.33 | 2.29 | 11.00 | 0.14 | 4.82-5.84 |
| Posterior offset (mm) | 3.37 | 1.98 | 9.10 | 0.30 | 2.91-3.83 |
| Curve length (mm) | 196.38 | 18.66 | 235.32 | 145.16 | 192.18-200.57 |
| Radius of curvature (mm) | 1,344.54 | 461.10 | 2,998.87 | 435.81 | 1,240.88-1,448.21 |
| Mediolateral angle (degree) | 7.83 | 3.50 | 15.01 | 0.8 | 7.05-8.62 |

STDEV = standard deviation
Max = maximum value
Min = minimum value

**Table 2.** Morphometric data of Thai humerus compared with 3D of Caucasian data(7,9)

| Data | Thai 3D (n = 76) | | Caucasian 3D based on CMM (n = 65) | | Caucasian 3D based on CT (n = 60) | |
|---|---|---|---|---|---|---|
| | Mean | STDEV | Mean | STDEV | Mean | STDEV |
| Diameter of humeral head (mm) | 42.65 | 4.21 | 46.20 | 5.40 | 46.00 | 2.00 |
| Diameter of articular surface (mm) | 40.51 | 3.88 | 43.30 | 4.30 | - | - |
| Articular surface thickness(mm) | 14.84 | 1.86 | 15.00 | 1.60 | 19.00 | 2.00 |
| Inclination angle (degree) | 127.64 | 4.28 | 129.60 | 2.90 | 131.00 | 3.00 |
| Retroversion angle (degree: B1) | 31.01 | 9.72 | 17.90 | 13.70 | 19.00 | 6.00 |
| Retroversion angle (degree: B2) | 33.89 | 9.71 | 21.50 | 15.10 | - | - |
| Medial offset (mm) | 5.33 | 2.29 | 6.90 | 2.00 | 7.00 | 2.00 |
| Posterior offset (mm) | 3.37 | 1.98 | 2.60 | 1.80 | 2.00 | 2.00 |
| Curve length (mm) | 196.38 | 18.66 | - | - | - | - |
| Radius of curvature (mm) | 1,344.54 | 461.10 | - | - | - | - |
| Mediolateral angle (degree) | 7.83 | 3.50 | - | - | - | - |

STDEV = standard deviation

The results showed that the Thai humerus was smaller than the Caucasian; however, the use of a smaller prosthesis may lead to several undesirable consequences. The ratio of articular surface thickness to the diameter of humeral head is a relationship of marked biomechanical importance. This ratio is proportional to the surface arc of the humeral head which, extrapolating from the planar measurement of this study, correlates with the articular surface area available for the glenohumeral joint. The contact between the prosthetic head and the glenoid articular surface may decrease earlier in the range of motion. The glenoid may not be able to capture a humeral head with which it is only partially in contact, leading to instability. Contact pressures may increase for a given joint reaction force, possibly accelerating wear of the glenoid. If these pressures are at the periphery of the glenoid, eccentric loading may promote glenoid loosening(1,18,25).

Currently, prostheses designs are based mostly on the Caucasian anatomical data. There is concern about mismatching in Thai patients. Use of a small size prosthesis in Thai patients was not suitable because of biomechanical consequences. The new design of the prosthesis based on the Thai population will solve the geometric mismatching or clinical complication in Thai patients.

## Conclusion

This advanced technique of computerized tomography combined with reverse engineering is useful to analyze the outer and inner geometrics with more accuracy than the other methods. These data include many significant parameters to use in prosthesis design and the prostheses design based on Thai data would minimize the possible complication during the operation or post-operation.

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## *การศึกษาข้อมูลทางกายวิภาคแบบ 3 มิติของกระดูกต้นแขนส่วนต้นในคนไทย: การศึกษาจากกระดูกศพ*

***ปัญญา อรุณจรัสธรรม, พงศนรินทร์ เจียมวัฒนชัย, บรรจง มไหสวริยะ, ธัญญะ เกียรติวัฒน์, กิตติ อรุณจรัสธรรม, กฤษณ์ไกรพ์ สิทธิเสรีประทีป***

*ในการศึกษานี้ได้ทำการหาข้อมูลทางกายวิภาคของกระดูกต้นแขนส่วนต้นของคนไทยจำนวน 76 ชิ้นตัวอย่าง โดยนำข้อมูลที่ได้จากการสแกนด้วยเครื่องเอกซเรย์คอมพิวเตอร์สามมิติและใช้เทคนิควิศวกรรมย้อนรอยในการขึ้นรูปโมเดลที่ทำการศึกษาเป็นสามมิติเพื่อหาค่าพารามิเตอร์ต่าง ๆ ของรูปทรงทั้งภายนอกและภายในของกระดูกต้นแขนคนไทย ค่าพารามิเตอร์ที่วัดได้จะถูกนำไปเปรียบเทียบกับค่าพารามิเตอร์ของชาวตะวันตก โดยค่าพารามิเตอร์ที่สนใจได้แก่ ขนาดเส้นผ่านศูนย์กลางของหัวกระดูกต้นแขน, ระยะความหนาพื้นผิวอาร์ติกูล่า, มุมอินคริเนชั่น, มุมเรโทรเวอร์ชั่น, ระยะออฟเซตจากตรงกลาง, ระยะออฟเซตจากด้านหลัง, ความยาวส่วนโค้งของโพรงกระดูก, รัศมีส่วนโค้งของโพรงกระดูก, และมุมเมดิโอแรทเทอรัล ผลที่ได้พบว่าค่าพารามิเตอร์ต่าง ๆ ของกระดูกต้นแขนคนไทยมีขนาดที่เล็กกว่าชาวตะวันตก ยกเว้นมุมเรโทรเวอร์ชั่นและระยะออฟเซตจากด้านหลัง โดยข้อมูลที่ได้สามารถนำมาใช้ในการพัฒนาวัสดุฝังในประเภทข้อเทียมของกระดูก ต้นแขนเพื่อให้ได้รูปทรงและขนาดที่เหมาะสมต่อกระดูกต้นแขนของคนไทยต่อไป*