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MRI-based anthropometric measurements of proximal humerus in Thai population

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Objective : *The objective of this project was to analyze the exact anatomical data collected from magnetic resonance imaging of Thai patients' shoulders and to compare their anatomical data with previous studies. Dimensions provided from this study can be used to assist implant manufacturers to evaluate the current and future designs.*

Setting : *Department of Orthopaedics, Faculty of Medicine, Chulalongkorn University*

Research design : *Descriptive study*

Patients : *Sixty-four shoulders / 58 patients who recieved MRI of the shoulder at Prachacheun Imaging Center from January 2008 – December 2008.*

Methods : *All anatomical data of the proximal humerus measured in 3D reconstruction of the MRI of patient shoulders. We used CATIA to measure all parameters and minimize the human errors by using a computer to calculate a 3D model*

Results : *The mean of total diameters of the articular was 36.64 ± 4.44 mm. The mean of the male and female shoulders were 40.83 ± 1.36 mm, 33.57 ± 2.76 mm respectively. Therefore, the difference between genders was significant. The mean articular thickness of the total*

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subjects was 15.48 ± 2.38 mm, i.e., the mean of the male; 16.83 ± 2.05 mm; and the mean of the female; 14.50 ± 2.13 mm. The difference of articular thickness between genders was also significant. The mean neck-shaft angle of all subjects was 137.71 ± 6.43 mm. Separately, the mean of the male and female subjects were 138.80 ± 4.86 mm, 136.92 ± 7.32 mm, respectively. The mean medial offset of all subjects was 5.43 ± 1.51 mm. It is explained that the mean of the male and female subjects were 5.29 ± 1.81 mm, 5.53 ± 1.26 mm, respectively. The mean posterior offset of all subjects was 1.15 ± 0.94 mm. We discovered the means of male and female subjects were 1.27 ± 0.80 mm, 1.06 ± 1.04 mm, respectively. The mean of all retroversion angles was 13.99 ± 16.17 mm. The means of the male and female subjects were 10.21 ± 16.16 mm, 16.76 ± 15.82 mm, respectively. Subsequently, the difference of neck-shaft angle, medial offset, posterior offset and retroversion angle between genders were not significant

Conclusion : *All data of this study when we compared to the previous in western population, we found significant difference in the diameter of the articular, neck-shaft angle, medial offset and posterior offset. This finding showed that an implant component suitable for using in western populations may not be compatible to the Thai population. The results of the project could provide fundamental data for the future design of shoulder prostheses suitable for the Thai population.*

Keywords : *MRI measurement, Proximal humerus, Thai population.*

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สุเมธ สุรัฐการดาวดี, พิบูลย์ อิทธิระวิวงศ์, สมศักดิ์ คุปต์นิรัติศัยกุล, ชัญญาพันธ์ วิรุฬห์ศรี. การวัดขนาดกระดูกต้นแขนส่วนบนในประชากรไทย โดยใช้ภาพถ่ายคลื่นรังสีสะท้อนในสนามแม่เหล็ก. จุฬาลงกรณ์เวชสาร 2553 ม.ค. – ก.พ.; 54(1): 39 – 56

วัตถุประสงค์ : *การศึกษานี้ต้องการที่จะได้ข้อมูลที่ถูกต้องทางกายวิภาคของข้อหัวไหล่ในประชากรไทยซึ่งได้มาจากการสร้างแบบจำลอง 3 มิติจากภาพถ่ายคลื่นรังสีสะท้อนในสนามแม่เหล็ก ข้อมูลที่ได้นำมาใช้เปรียบเทียบกับการศึกษาก่อนหน้านี้ ในกลุ่มประชากรตะวันตก ข้อมูลที่ได้ยังสามารถนำไปใช้เป็นพื้นฐานในการผลิตข้อหัวไหล่เทียมที่เหมาะสมกับกลุ่มประชากรไทยต่อไป*

สถานที่ทำการวิจัย : *ภาควิชาออร์โธปิดิกส์ คณะแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย*

รูปแบบงานวิจัย : *การศึกษาแบบพรรณนา*

การคัดเลือกผู้ป่วย : *คนไข้ที่ทำการถ่ายภาพคลื่นรังสีสะท้อนในสนามแม่เหล็กของข้อหัวไหล่ระหว่างเดือนมกราคม 2551 ถึง เดือนธันวาคม 2551 ที่ศูนย์บริการตรวจวินิจฉัยโรคด้วยเครื่อง Magnetic Rasonance Imaging (MRI) ประชาชื่น มีจำนวน 64 หัวไหล่ ในคนไข้ 58 คน*

ระเบียบวิธีการวิจัย : *ข้อมูลการวัดขนาดทางกายวิภาคของส่วน proximal humerus โดยนำภาพจาก MRI ของข้อหัวไหล่ในคนไข้ มาสร้างเป็นภาพ 3 มิติ และใช้โปรแกรม CATIA วัดค่าต่าง ๆ ข้อมูลที่ได้บันทึกเป็นค่าเฉลี่ย, ส่วนเบี่ยงเบนมาตรฐาน*

ผลการศึกษา : *ค่าเฉลี่ยของ diameter of articular ของกระดูกต้นแขนรวมทั้งหมดคือ 36.64 ± 4.44 มม.โดยแบ่งเป็นค่าเฉลี่ยในเพศชาย 40.83 ± 1.36 มม. ในเพศหญิง 33.57 ± 2.76 มม. โดยพบว่ามีความแตกต่างอย่างมีนัยสำคัญทางสถิติ, ค่าเฉลี่ยของ articular thickness ของกระดูกต้นแขนรวมทั้งหมดคือ 15.48 ± 2.38 มม. โดยค่าเฉลี่ยในเพศชาย 16.83 ± 2.05 มม. ในเพศหญิง 14.50 ± 2.13 มม. โดยพบว่ามีความแตกต่างอย่างมีนัยสำคัญทางสถิติ, ค่าเฉลี่ยของมุม neck-shaft angle ในกระดูกต้นแขนรวมทั้งหมดคือ 137.71 ± 6.43 มม. ค่าเฉลี่ยในเพศชาย 138.80 ± 4.86 มม. ค่าเฉลี่ยในเพศหญิง 136.92 ± 7.32 มม., ค่าเฉลี่ยของ medial offset ของกระดูกต้นแขนรวมทั้งหมดคือ 5.43 ± 1.51 มม. ค่าเฉลี่ยในเพศชาย 5.29 ± 1.81 มม. ค่าเฉลี่ยในเพศหญิง 5.53 ± 1.26 มม., ค่าเฉลี่ยของ posterior offset ของกระดูกต้นแขนรวมทั้งหมดคือ 1.15 ± 0.94 มม. ค่าเฉลี่ยในเพศชาย*

1.27 ± 0.80 มม. ค่าเฉลี่ยในเพศหญิง 1.06 ± 1.04 มม., ค่าเฉลี่ยของ retroversion angle ของกระดูกต้นแขนรวมทั้งหมดคือ13.99 ± 16.17 มม. ค่าเฉลี่ยในเพศชาย 10.21 ± 16.16 มม. ค่าเฉลี่ยในเพศหญิง 16.76 ± 15.82 มม. โดยพบว่าไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติระหว่างเพศชายและหญิงของค่าเฉลี่ยของ neck-shaft angle, medial offset, posterior offset, retroversion angle ในการศึกษานี้ได้มีการเปรียบเทียบข้อมูลระหว่างข้างและกลุ่มอายุพบว่าไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติในทุกค่าเฉลี่ย

ผลสรุป : *ค่าที่ได้ทั้งหมดจากการศึกษานี้เมื่อนำไปเปรียบเทียบกับการศึกษาก่อนหน้านี้ที่เป็นการศึกษาในกลุ่มประชากรตะวันตก (western population) พบว่าค่าเฉลี่ยของ diameter of articular, neck-shaft angle, medial offset and posterior offset มีความแตกต่างอย่างมีนัยสำคัญทางสถิติ จากผลการศึกษาสรุปได้ว่าข้อหัวไหล่เทียมที่เหมาะสมกับประชากรแถบตะวันตกไม่เหมาะสมที่จะนำมาใช้กับกลุ่มประชากรไทยผลลัพธ์จากการวิจัยครั้งนี้สามารถนำไปเป็นข้อมูลพื้นฐานในการออกแบบข้อเข่าเทียมที่เหมาะสมกับประชากรไทยต่อไป*

คำสำคัญ : *ภาพถ่ายคลื่นรังสีสะท้อนในสนามแม่เหล็ก , กระดูกต้นแขนส่วนบน, ประชากรไทย.*

Shoulder arthroplasty has been established for several decades to restore comfort and function of the shoulder for many afflictions that derange the normal anatomy. Rigorous study of shoulder anatomy in terms was relevant to prosthetic geometry, however, did not begin until the 1990s. It had become apparent that normal anatomy was highly variable from individual to individual and variable from left to right in the same individual that it was aligned somewhat differently than the early modular prosthetic devices. Several studies have shown that retroversion was markedly variable ranging from 0 degree to 55 degrees. The inclination of the proximal humeral articular surface relative to the shaft (head shaft angle) was also variable, ranging from 30 degrees to 55 degrees. The center of rotation was variably offset in 3 dimensions. The radius of curvature ranges from 20 to 30 mm and was smaller in women than in men. The thickness of the articular surface, head height, was equally variable but showed a striking proportionality to the radius of the curvature. The last decade has seen a proliferation of humeral implants aiming to serve a better understanding of variation of the shoulder anatomy. The second and third generations have occurred and more modules of implant for surgeons to selected. Head size selection was dependent on multiple factors. The selection of head size is the most important of these, other than the patient's original head size, was the osteotomy performed by the surgeon and the inclination angle(s) of the prosthetic system. Systems with variable inclination angles instruct the surgeon to resect the humeral head along the anatomic neck as best possible and then provide either adjustable or variable prosthetic geometries to match the resultant inclination angle. Other prosthetic systems had a fixed inclination angle somewhere within the normal range and instruct the surgeon to make an osteotomy at this inclination, adjusting the fit with additional preparation of the canal and revising the osteotomy as necessary. So many surgeons with experience using modern systems feel a greater sense of predictability in achieving their surgical goals to anatomical reconstruction when using these systems as compared with the earlier ones.

Anatomical reconstruction was termed to call surgery that restores the same or nearly same anatomical and dimension of patient's shoulder. This helps to avoid complications and maximizes outcome. Nowadays we have many cases that perform shoulder arthroplasty but there is no data concerning about morphological dimensions of the proximal humerus in this population. Every shoulder prosthesis system is designed for western population and has been introduced to use in Thai and Asian populations without specific modification. The objective of this study was to compare the anthropometric data of proximal humerus in Thai population with the western population data and compare with the dimensions of the current shoulder prosthetic systems.

Objective

The objective of this project was to analyze the exact anatomical data collected from Magnetic Resonance Imaging of Thai patients' shoulders and to compare the anatomical data with previous studies. Dimensions provided from this study can be used to assist implant manufacturers in evaluating the current and future prosthesis designs.

Literatures review

The shoulder implants system that is designed to mimic the normal anatomy would provide the best function and durability. However, the original Neer prosthesis was only available in a limited range of sizes, the first generation shoulder prosthesis. Fluoroscopic studies showed that the ability to reproduce the normal kinematics of the glenohumeral joint with such an implant was limited.[1] In the early 1990s modular, or second generation prostheses were developed (Biomet, Cofield, Global) to match a wide variation observed in the dimensions of the head and the diameter of the medullary canal. Unfortunately, their concept and design did not achieve the normal anatomy and two major problems were encountered. First, the prosthetic head was often malpositioned in both the vertical and the horizontal planes. This was because of their relatively fixed geometry. Most of them were uncemented and because they were press-fit; the position of the stem dictated the head, leading in certian instances to displacement of the center of rotation outside its normal position. Secondly, the head was frequently oversized. The heads usually came in differing depths but with the same diameter, leading the surgeon to implant excessively large prostheses. Studies[2, 3] have shown that there was a linear relationship between the depth and the diameter so that only one depth could go with one diameter, except that the heads are larger than 50 mm in diameter. Another reason for oversizing was the gap between the osteotomy and the prosthetic head. Pearl and Kurutz,[4] in a three-dimensional analysis, noted that even when this gap was eliminated and optimal prosthetic version was achieved, there was still a displacement of the center of rotation greater than 5 mm despite their modularity. The second-generation prostheses did not allow replication of the proximal humeral anatomy and even created new problems not seen in the Neer prosthesis. When a head is changed too large, the biomechanics is aitered by over-tensioning the joint. This limits the mobility and possibly of wearing the glenoid cartilage with a hemiarthroplasty or wearing of the polyethylene if the glenoid is resurfaced. The associated excessive tension in the rotator cuff may lead either to an early rupture of the repaired subscapularis and possible anterior instability, or later stretching or tearing of the supraspinatus, causing pain and loss of active elevation. Inaccurate reproduction of the geometry of the proximal humerus may induce abnormal function of the abductor muscles and change the lever arms around the glenohumeral joint. Nyffeler *et al*.[5] have shown that if the center of the head lies too superiorly to the subscapularis and the infraspinatus are converted from abductors into adductors, substantially increasing the load on the supraspinatus in elevation and abduction. Alteration of the bone anatomy by changing the humeral retroversion may lead to eccentric loading at the periphery of the glenoid, which may increase glenoid wearing with subsequent loosening.[5] This may explain the rapid deterioration of the clinical results in some patients with second-generation arthroplasties.[6] Boileau and Walch[2] and others,[7] have shown that the shape of the proximal humerus is more complex than has been described previously. Roberts *et al*.[8] and Wallace *et al*.[9] observed that the articular surface of the head was offset posteriorly compared with the proximal medullary axis. If a prosthesis is to reproduce normal anatomy, its head must also be offset. We found that the articular surface was also medially offset in relation to the proximal medullary axis and that the head was variably orientated in the vertical and horizontal planes.[2] Therefore, it must be possible to offset the head posteriorly and medially and to vary its inclination and retroversion. These findings led to modifications in the design of the prosthesis in the surgical technique. Identifying the true anatomical neck became the critical step. This was achieved by careful removal of the crown of osteophytes around the head. The anatomical neck could be visualized even in the presence of severe erosion of the head. Better understanding of the anatomical relationships within the normal gleno-humeral joint has resulted in improvements in design of unconstrained prostheses so that the three-dimensional geometry of the proximal humerus can be recreated, the third generation prostheses. The principle of correct positioning of the prosthetic head to mimic an individual's anatomy is described as 'adaptability', and clinical results using this implant have been published to validate this view.[10, 11] Subsequent research with other third-generation implants, both modular and adaptable, has confirmed the importance of recreating the unique of each patient's anatomy.[8,12 – 16] Part of the principle of design in the third generation implants is matching the depth of the head to its diameter. We now know that displacement of the joint surface leads to altered kinematics and decreases gleno-humeral movement, causing translation of the head of the humerus.[14 - 16] Selecting the appropriate size of head is important since biomechanical experiments have shown that a change in the center of rotation of 5 mm to 10 mm results in significant reduction of the lever arms of the deltoid and rotator-cuff muscles during abduction. Harryman *et al*. have shown that an increase in the depth of the head by only 5 mm decreases the range of gleno-humeral movement by 20 degrees to 30 degrees. Decreasing the depth by 5 mm reduces the gleno-humeral excursion by 24 degrees.[13] Using an oversized head component results in a substantial reduction of joint laxity and severe limitation of flexion, abduction and external and internal rotation. Other aspects of the anatomy of the proximal humerus need to be considered in trying to design an anatomical prosthesis. If the individual neck-shaft angle is not respected, the length of the abductor muscles may be altered resulting in abnormal function. Therefore, the implant must offer this option in order to restore the lever arms of the deltoid and supraspinatus. Boileau *et al.*[2] study has noted that the provision of four stem-neck angles (125 degrees, 130 degrees, 135 degrees and 140 degrees) encompasses more than 95 percent of patients. By resecting the humeral head at the anatomical neck and using an implant which can be constructed to match the retroversion, inclination and medial and posterior offset with an identical depth of head, the individual lever arms of the rotator cuff muscles are restored. This 'anatomical reconstruction' of the joint results in normal kinematics and kinetics. The third generation systems can recreate structure and geometry which matches the normal anatomy to a greater extent than those of the second-generation.[4, 17]

Materials and Methods

Patient selection

All Thai patients performed MRI of shoulders at Prachacheun Imaging Center from January 2008 –

December 2008. The inclusion criteria were: older than 20 years old (skeletal maturation), having no bone destruction on imaging. Congenital and acquired bony deformity, previous shoulder surgery, other inflammatory joint disease were excluded. Eighty-two shoulders that performed MRI were collected and reviewed history and plain radiograph. Eighteen shoulders were excluded as previous shoulder surgery (5), bony deformity (13). Sixty-four shoulders were classified according to age, gender and side. Demographic data are shown in Table 1.

Sample size estimation

Data collection type : continuous data

Sample size estimation (N) = $(Z^2)(sigma^2) / d^2$

Z = 1.96 (z score at 95% confidence interval)

Sigma = 13.7 (variance from the most deviation data on previous study)

d (clinical difference) = 3.58 (calculated from 20% difference of the most deviation data)

estimated size (N) = $(1.96)^2(13.7)^2 / (3.58)^2$ = 56.258 data from previous study on anthropometric measurement Boileau P, Walch G[2]

MRI measurements

The patient was performed by using MRI SIEMENS machine (Avanto version VB15 18 channels, Germany), magnetic field 1.5 Tesla whole body MR Imaging system with an extremity coil. The pulse sequences were T1-weighted images. The position of the arm performed MRI was controlled by epicondylar axis. The coronal view was sliced parallel to this axis and the sagittal was perpendicular to this axis. The direction of the axial slice imaging placed the slice perpendicular to the humeral shaft axis in the coronal and sagittal planes. All images were reconstructed at 1.5 mm slice thickness. Image parameter use 3D Flash, FOV (Field of View) 17x17 cm, matrix 512x512 pixels, coronal oblique plane flip angle 50 degrees, coil shoulder array TR/TE = 30/5.6. All images were collected in DICOM files to reconstruct in three dimensions.

Table 1. Demographic data.

Demographic data	Statistical data
No. of shoulders, patient	64, 58
Age (average, yr)	47.266 ± 9.41
Age (min-max, median)	24-60, 48.5
Weight (average, kg)	62.695 ± 10.92
Height (average, cm)	163.344 ± 7.72
Gender, Age (male / female)	27 / 37, 45.85 / 48.30
Gender, Weight (male / female)	27 / 37, 69.11 / 59.01
Gender, Height (male / female)	27 / 37, 168.78 / 159.38
Side, Age (rt / lt)	33 / 31, 47.56 / 46.97
No. of patient Age 21 – 40, average age	11, 30.455 ± 9.95
No. of patient Age 41 – 60, average age	53, 50.755 ± 9.41

3D image reconstruction

The MRI data were reconstructed in 3D with Materialize version 11.11 (Mimic). After the images were imported in three views (coronal, sagittal and coronal oblique), dynamic region growing and multiple-slices editing were performed to fill colors in the bone contrast all view of humerus (see Fig. 1). Computer software could calculate 3D image precisely and surface reconstruction to 3D model of the humerus. Exported file.stl data from Materialize and saved in file.igs or file.stp. Convert 3D Crown Point and section precisely at the margin of cartilage at humeral head. Crown Point humeral shaft was section in proximal part and distal part. All sectioned 3D Crown Point was saved in file.text and exported in file.igs.

Axis and pane identification

The exported data were imported by CATIA version 15 R18 and computerized calculated for axis and plane. 3D Crown Point was a quick surface reconstruction by a computer with the best fitting sphere and best fitting cylinder. The center of the sphere and the axis of the cylinder were calculated and the co-ordinate saved. Join surface reconstruction was performed by wireframe and surface design to solid 3D model. Center and axis were paste on the solid 3D model in the same co-ordinate and we identified as center of humeral head, axis of proximal humerus and axis of distal humerus. The distal humerus was resected to identify the coronal plane from the supracondylar ridge that continues from the epicondylar eminence. Three levels of resection and each level had two points that continue to the supracondylar ridge, identified by the most medial and lateral points after tangency of two vertical lines to the medial and lateral sides of the distal humerus. The coronal plane was reconstruction by the means through point functions (3 medials, 3 laterals) using the coronal plane and rotate axis of the humeral shaft to the vertical line to identify the Antero-posterior (AP) view of a 3D model of the humerus.

The anatomical neck plane was that best fitting the periphery of cartilage in AP view and axial view, identified by the point abrupt change in curvature at the humeral head.

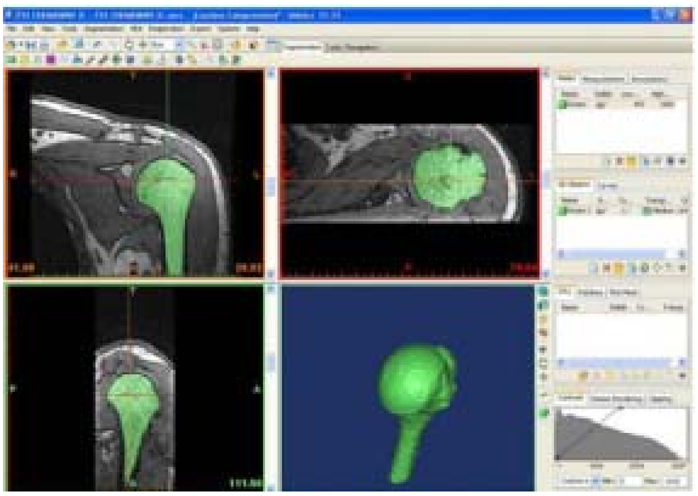

Figure 1. Three views of MRI in Materialize and 3D reconstruction.

The epiphyseal sphere was computerized calculation best fitted with articular surface of humeral head, and the center of the sphere was calculated as center of the humeral head.

The proximal humeral cylinder was the cylinder which the best fitted with the proximal shaft of humerus. The defined point is a change in curvature down to humeral shaft. Axis of proximal shaft of humerus was calculated.

The humeral head axis was defined as the line perpendicular to the anatomical neck plane to the apex of articular surface in both axial and AP view.

Apex of articular surface identified by the most prominence point after tangency the line to the articular surface in both axial and coronal view.

The diaphyseal humeral axis was defined as the axis of midshaft and distal of humerus, use in resection perpendicular to this axis to identify coronal plane.

The proximal humeral shaft axis is axis of proximal cylinder of humerus. It represents axis of stem of prosthesis and use in defined neck shaft angle, mediolateral offset, Anteroposterior (AP) offset.

The coronal plane defined by medial and lateral epicondylar ridge and the vertical humeral shaft axis to identify AP view of humeral model.

The axial plane defined as plane perpendicular to coronal plane and humeral shaft axis, computer calculated by rotation X-axis and 90 degrees angle to coronal axis.

Measured parameter

The important anatomical humeral parameters were measured by CATIA version 15R18 (length in mm, angle in degree). Data were recorded individually (Fig. 2-3).

1) The diameter of the humeral head, diameter of curvature defined as diameter of sphere that best fit the curvature in both the coronal and axial planes.

2) The diameter of the articular surface in both the coronal and axial planes, defined as the diameter of the articular surface at the level of the margin of the articular cartilage (anatomical neck plane). The level of measured diameter as a level of osteotomy site when shoulder arthroplasty was

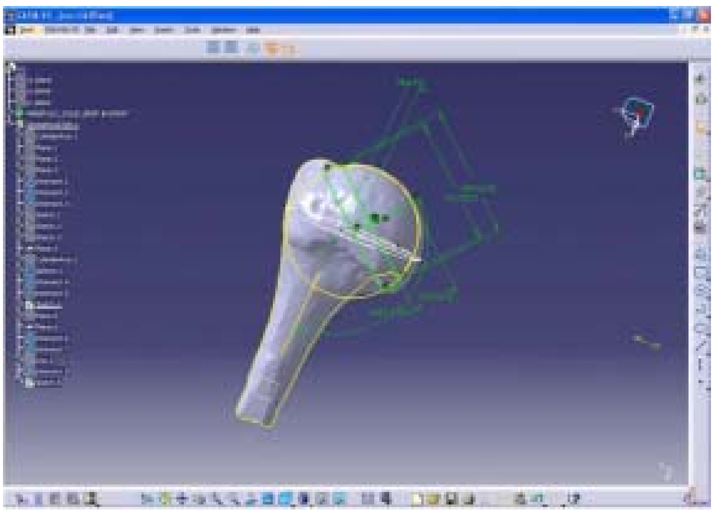

Figure 2. Measurement parameters in the coronal plane.

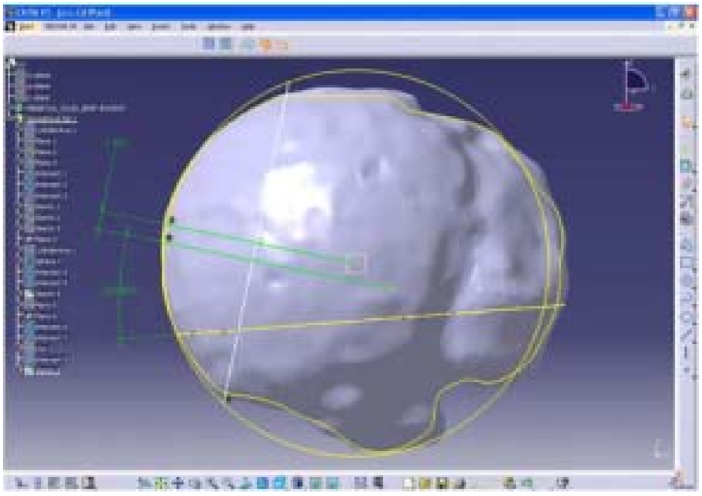

Figure 3. Measurement parameters in the axial plane.

performed.

3) The thickness of the humeral head, distance perpendicular from anatomical neck plane to the apex of the articular surface.

4) The neck-shaft angle, angle between humeral head axis and the proximal humeral axis.

5) The medial offset is defined as the perpendicular distance between the center of the epiphyseal sphere and the central axis of the proximal humeral axis.

6) The retroversion angle is the angle between the humeral head axis in the axial view and the coronal plane axis (referred to as the ransepicondylar axis).

7) The posterior offset which is the perpendicular distance between the center of the epiphyseal sphere in the axial view and the central of the proximal humeral axis in the axial view.

Statistic analysis

All the measured parameters were recorded in millimeters and used mean ± standard deviation to represent result of this study. The results were analyzed between age groups, genders and sides. Statistical analysis of the parameters included two-tailed student t-test and p value option. We identified type I error as 0.05 and type II error as 0.2. A p value < 0.05 indicated a significant difference. Regression analysis was used to determine a correlation between two parameters of the proximal humerus and the prosthesis systems. Correlation co-efficiency was use to analyze and determine the correlation between a prosthesis and gender. All statistical analyses were performed by SPSS for Windows version 13.0 and STATA version 10.0.

Results

The proximal humerus structure

The results of measurements were classified in total group and subgroup analyses according to gender, side and age group. The diameter of curvature (diameter of best fitted sphere) varied from a minimum of 28.6 mm to a maximum of 46.32 mm. The mean and standard deviation of the diameter of the sphere were 37.43 ± 4.40 mm and in male and female were 41.66 ± 2.63 mm and 34.33 ± 2.38 mm, respectively. The mean and standard deviation of the diameter of the articular surface were 36.64 ± 4.44 mm and in male was 40.83 ± 2.36 mm, in the female was 33.57 ± 2.76 mm that minimal less than the curvature. Depth of the articular surface (humeral head thickness) was 15.48 ± 2.48 mm. The depth of the male was 16.83 ± 2.05 mm and in female was 14.50 ± 2.13 mm (Table 2). Having analyzed the diameters of the articular surface and articular thickness, linear correlation, regression analysis can be determined. The equation of regression analysis was: $y = 0.335 x + 2.450$; and x was the diameter of articular surface whereas y was articular thickness. Regarding the gender, the diameter of both the sphere and articular and articular surface thickness in the male were larger than that of the female (Fig. 4). The difference in these three parameters were significant ($p < 0.0001$) (Table 4). So, gender was a very important factor of the diameter and articular thickness of the proximal humerus. The results of this study is compared to a previous study done by Boileau P. *et al*. (Table 5.), we found a significant difference in the diameter of the sphere, the diameter of the articular surface but no statistical difference in the articular thickness. Therefore, the result of this study supports the hypothesis that the diameter of the humeral head in the Thai population was smaller than that reported in a previous study (western population).

See table 3, the neck-shaft angle with respect to the proximal metaphysic axis had minimum of 110.89 degrees to maximum of 151.45 degrees. The mean and standard deviation of neck-shaft angle were 137.71 ± 6.43 degrees. We found no difference of this angle between the genders. The mean and standard deviation of the medial offset was 5.43 ± 1.51 mm.. We also found no difference of the medial offset between genders. Regarding the posterior offset, we found the offset range from anterior offset 2.23 mm to posterior offset 3.02 mm. Two patients had anterior offset (-2.23 mm,-0.62 mm) and both of them had retroversion. We can imply that no relation between the anterior offset and the anteversion or retroversion. The retroversion angle, with respect to the coronal plane, this study had the range from anteversion of 25.42 degrees to retroversion of 52.43 degrees. The mean and standard deviation of retroversion angle was 13.99 ± 16.17 degrees. The result showed a high standard deviation of this parameter and had a wider range of the angle. The retroversion angle had high individual difference that cannot use some degrees of the angle as reference to all patients. Nine patients of sixty-four patients (14.06%) had anteversion angle. The difference of these four parameters (neck-shaft angle, medial offset, posterior offset and retroversion angle) between genders (Table 4). Therefore, genders were not important factors for these four parameters in proximal humeral prosthesis selection. When compared the result of this study to a previous study of Boileau P. *et al*. (Table 5), the neck-shaft angle was significant difference, the medial offset was significant difference, the posterior offset was significantly different and the retroversion angle showed no statistical difference. This study supported the difference between the western and the Thai population.

Table 2. Diameter of the sphere and articular surface and articular thickness (mm).

	Diameter of sphere (mm.)	Diameter of articular surface (mm.)	Articular thickness (mm.)
Total	37.43 ± 4.40	36.64 ± 4.44	15.48 ± 2.38
	(28.46 - 46.32)	(24.24 - 45.43)	(8.75 - 20.22)
Male	41.66 ± 2.63	40.83 ± 2.36	16.83 ± 2.05
	(36.80 - 46.32)	(36.60 - 45.43)	(11.92 - 20.22)
Female	34.33 ± 2.38	33.57 ± 2.76	14.50 ± 2.13
	(28.46 - 39.71)	(24.24 - 39.69)	(8.75 - 19.21)
Right side	38.05 ± 4.26	37.16 ± 4.40	15.73 ± 2.27
	(28.46 - 46.32)	(24.24 - 45.43)	(11.24 - 20.21)
Left side	36.76 ± 4.52	36.08 ± 4.48	15.22 ± 2.51
	(30.54 - 44.92)	(28.81 - 44.00)	(8.75 - 20.06)
Age 21 - 40	39.39 ± 4.87	38.72 ± 4.81	16.56 ± 2.89
	(32.35 - 46.16)	(31.35 - 44.00)	(13.32 - 20.08)
Age 40 - 60	37.02 ± 4.25	36.20 ± 4.28	15.26 ± 2.20
	(28.46 - 46.32)	(24.24 - 45.43)	(8.75 - 20.22)

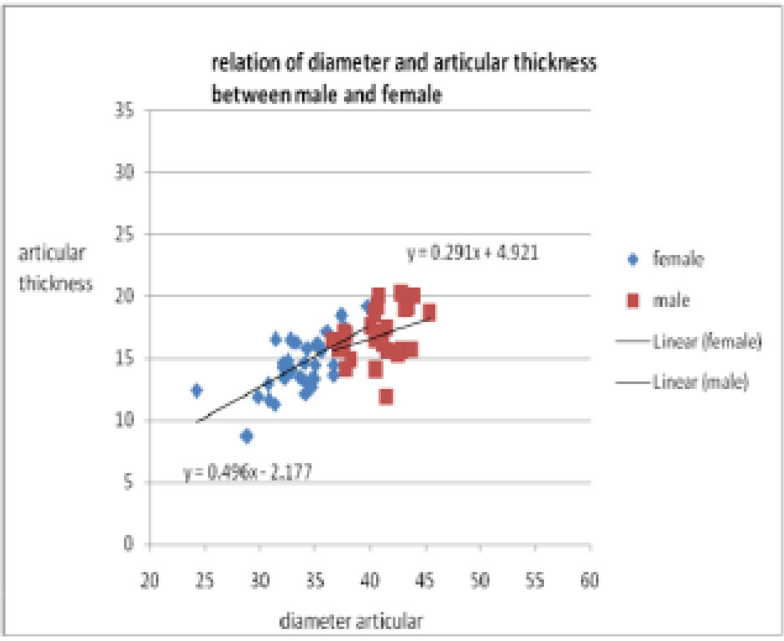

Figure 4. Graphic demonstration of the relation of diameter and articular thickness between males and females.

Table 3. Neck-shaft angle, medial offset, posterior offset and retroversion angles.

	Neck-shaft angle	Medial offset	Posterior offset	Retroversion angle
Total	137.71 ± 6.43	5.43 ± 1.51	1.15 ± 0.94	13.99 ± 16.17
	(110.89 - 151.45)	(1.49 - 10.32)	(-2.23 - 3.02)	(-25.42 - 52.43)
Male	138.80 ± 4.86	5.29 ± 1.81	1.27 ± 0.80	10.21 ± 16.16
	(129.71 - 145.92)	(1.49 - 10.36)	(0.04 - 2.76)	(-25.42 - 44.51)
Female	136.92 ± 7.32	5.53 ± 1.26	1.06 ± 1.04	16.76 ± 15.82
	(110.89 - 151.45)	(2.84 - 8.18)	(-2.23 - 3.02)	(-11.51 - 52.43)
Right side	137.72 ± 5.43	5.49 ± 1.65	1.29 ± 0.80	15.82 ± 16.10
	(124.08 - 147.75)	(1.88 - 10.32)	(0.15 - 2.76)	(-12.06 - 52.43)
Left side	137.70 ± 7.44	5.36 ± 1.37	1.00 ± 1.07	12.05 ± 16.27
	(110.89 - 151.45)	(1.49 - 7.82)	(-2.23 - 3.02)	(-25.42 - 48.14)
Age 21- 40	136.72 ± 4.81	6.17 ± 1.36	1.39 ± 1.01	8.92 ± 12.79
	(128.40 - 143.12)	(3.69 - 8.18)	(0.04 - 3.02)	(-14.90 - 24.17)
Age 40 - 60	137.92 ± 6.80	5.27 ± 1.52	1.10 ± 0.94	15.05 ± 15.86
	(110.89 - 151.45)	(1.49 - 10.32)	(-2.23 - 2.76)	(-12.06 - 52.43)

Table 4. Comparison of the parameters between genders.

	Female	Male	P value
Diameter of sphere	34.33 ± 2.38	41.66 ± 2.63	P <0.0001
	(28.46 - 39.71)	(36.80 - 46.32)	
Diameter of articular	33.57 ± 2.76	40.83 ± 2.36	P <0.0001
	(24.24 - 39.69)	(36.60 - 45.43)	
Articular thickness	14.50 ± 2.13	16.83 ± 2.05	P <0.0001
	(8.75 - 19.21)	(11.92 - 20.22)	
Femoral neck-shaft angle	136.92 ± 7.32	138.80 ± 4.86	0.249
	(110.89 - 151.45)	(129.71 - 145.92)	
Medial offset	5.53 ± 1.26	5.29 ± 1.81	0.539
	(2.84 - 8.18)	(1.49 - 10.36)	
Posterior offset	1.06 ± 1.04	1.27 ± 0.80	0.388
	(-2.23 - 3.02)	(0.04 - 2.76)	
Retroversion angle	16.76 ± 15.82	10.21 ± 16.16	0.111
	(-11.51 - 52.43)	(-25.42 - 44.51)	

Table 5. Comparison of the parameters between this and a previous study[2]

	This study	Boileau P. et al.	P Value
Diameter of sphere	37.43 ± 4.40	46.2 ± 5.4	P <0.001
	(28.46 - 6.32)	(37.1 - 56.9)	
Diameter of articular	36.64 ± 4.44	43.3 ± 4.3	P <0.001
	(24.24 - 45.43)	(36.5 - 51.7)	
Articular thickness	15.48 ± 2.38	15.2 ± 1.6	0.436
	(8.75 - 20.22)	(12.1 - 18.2)	
Femoral neck-shaft angle	137.71 ± 6.43	129.6 ± 2.9	P < 0.001
	(110.89 - 151.45)	(123.2 - 135.8)	
Medial offset	5.43 ± 1.51	6.9 ± 2.0	P <0.001
	(1.49 - 10.32)	(2.9 - 10.8)	
Posterior offset	1.15 ± 0.94	2.6 ± 1.8	P <0.001
	(-2.23 - 3.02)	(-0.8 - 6.1)	
Retroversion angle	13.99 ± 16.17	17.9 ± 13.7	0.143
	(-25.42 - 52.43)	(-6.7 - 47.5)	

Discussion

At present, the best result of the shoulder arthroplasty is to restore the anatomical structure of the normal patient shoulder. The accurate size of the implant and the position when we placed the prosthesis can minimize the stress on the bone implant interface and had good mechanical and good arthro-kinematics of the shoulder joint.

Many parameters affect to the accuracy of the anatomical reconstruction and accuracy of the placed prosthesis. In the preoperative planning for the prosthesis size, It was difficult to measure because of the destruction of the bone from the fracture or the arthritis change that alters the normal anatomy of the proximal humerus. So we usually either under- or overestimate the size of the head and the thickness of the articular. Our study had the average diameter and the thickness of each gender that were performed in the Thai population and can be used in the case that preoperative radiographs are not possible. We also found that the diameter of the articular and the thickness of the articular in the female were significantly smaller than in that in the male. The neck-shaft angle, the retroversion angle, the medial offset and the posterior offset were the variable parameters because of the variable orientation. Restoration of the normal anatomy during arthroplasty may be difficult with the relatively fixed geometry of the existing prosthesis system. The widest parameter range was the retroversion (from anteversion to retroversion). Failure to match the shape of the head potential biomechanical consequences is due to a malposition of the joint line and the moved center of rotation.

In this study, the average of diameter of articular surface was significantly smaller than that of a previous study done in the western populations. Not only the diameter of the sphere and the articular, but also the medial, posterior offset and neck-shaft angles were significantly different. The neck-shaft angle in the Thai population was significant higher than that described in the previous study. Regarding the offsets in the Thai population, there were more medial but less posterior offset than that reported by the previous one. Therefore, the proximal humerus dimension in the Thai population was significantly different to that of the western. Because of these differences, the prostheses that are suitable for the western population were not suitable for the Thais.

To correct the wide range of parameters that affect to the orientation of the prosthesis, surgical technique could compensate these variations. The limitation of the inclination (neck-shaft angle) of the prosthesis; 134 degrees and 138 degrees were not suitable for everyone. According to this study, the inclination had wider range and had more variation in individuals. Therefore, the fixed humeral cut in all patients will displace the center of rotation proximally and alter arthrokinematics. Some studies[18] recommended to orientation the inclination to the original true anatomical neck plane. This is more appropriate to individual shoulder. Concerning the retroversion, the angle between the anteversion of 25.42 to retroversion 52.23 degrees, the anatomical reconstruction of the retroversion angle should be individualized. The prosthesis retroversion cut was limited between 20 - 40 degrees to the tranepicondylar axis. Therefore, the landmark of the cut was the true anatomical neck plane was more appropriate. The medial and posterior offset also had a wide range and more variation among patients. Boileau *et al.*[19] recommended choosing of a smaller stem to translate the medial or posterior or both. The varus placement of a smaller stem could correct the variation of the medial offset and its inclination. The other technique was to resect more bone posteriorly to allow an increase in the posterior offset and retroversion.

The third generation shoulder prosthesis is not only modular but also adaptable to individual bone anatomy. Adaptable prosthesis allows to correct placement of the implant and restore normal anatomy and kinematics. Nowadays, in Thailand, the second generation prosthesis was currently used as the third generation prosthesis is not available in Thailand. According to this study, the data may be useful for the manufacturer to design new systems of prosthesis for the Thai and Asian populations. The size difference between genders and various articular thickness in adaptable prosthesis will be more appropriate. This is a custom-made prosthesis supported by this concept for anatomical reconstruction. The image process of this study can be used to for a 3D reconstruction of the individual's shoulder anatomy from MRI before the surgery is performed, that can evaluate the size and plan for positioning of the implant. This process may be both useful for preoperative planning and implant selection in the future.

Conclusion

The most common complication of shoulder arthroplasty is stiffness and wear of the glenoid component. Its common cause is the mismatch and malpositioned between the implant and the patient original bone. Proper implant sizing and correct positioned can improve surgical outcome and longevity of the prosthesis. This study shows that an implant is more suitable for the western and not suitable for the Thai population as the stature of the Thai and Asia-pacific populations. The appropriate prosthesis size must be smaller than that used today. The best result with restore normal anatomy was reported in the adaptable third generation prosthesis.[17] The objective of this study was to obtain anthropometric data on the proximal humerus to design the optimal component for the Thai and Asia-pacific population. The result of this study could provide fundamental data for the design of shoulder prosthesis that is more suitable for the target population. The image reconstruction process form MRI of this study may help in preoperative planning for shoulder arthroplastic surgery that is more specific and useful than plain radiographs alone.

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