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Geometric analysis of the humeral head and glenoid in the Indian population and its clinical significance

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Background: Total anatomic and reverse shoulder prostheses are designed to match the dimensions of the native bony anatomy. Chinese and Japanese bony dimensions of the shoulder have been found to be different from that of the Caucasian population. We hypothesized that the geometric dimensions of the humeral head and glenoid in the Indian population would also be different from that of the Caucasian population.

Method: Fifty patients underwent computerized tomographic scans of their normal shoulders. We calculated the superoinferior (SI) diameter of the humeral head, anteroposterior diameter of the humeral head, radius of curvature of the humeral head, humeral head retroversion, humeral head thickness, inclination angle, critical shoulder angle, greater tuberosity angle, glenoid width, glenoid length, radius of curvature of the glenoid, glenoid inclination angle, and glenoid version.

Results: The radius of curvature of the humeral head averaged 22.9 ± 1.7 mm, the articular surface thickness 17.1 ± 1.6 mm, and the SI diameter 42.3 ± 3 mm. The SI diameter strongly correlated with the thickness ($r = 0.617$, $P = .001$). The anteroposterior/SI articular surface diameter ratio averaged 0.9 ± 0.9, the articular surface thickness/radius of curvature ratio 0.7 ± 0.9, the inclination angle 133.8 ± 6.4, and the retroversion angle 33.5° ± 8.5°. The radius of curvature of the glenoid averaged 23.3 ± 3.4 mm, the glenoid width 24.0 ± 2 mm, the SI length 31.3 ± 2.2 mm, the glenoid inclination angle 78.7° ± 4.8°, and the glenoid retroversion 1.8° ± 3.8°.

Discussion: Compared with the Western population, our cohort had a smaller humeral radius of curvature ($P = .04$), smaller articular surface diameter ($P = .001$), smaller inclination angle ($P = .003$), larger retroversion angle of the humeral head ($P < .001$), and smaller glenoid length and width ($P < .0001$). Most of the implant companies did not have smaller sized combinations of humeral heads with thickness to match our population. The glenoid width of females in our cohort was found to be smaller for the smallest size of the glenoid base plate.

Conclusion: Smaller sized options in humeral head diameter and thickness of the anatomic prosthesis and glenoid baseplate of the reverse shoulder prosthesis need to be made available to suit our population and avoid a mismatch.

Total anatomic and reverse shoulder replacement prostheses are designed according to the dimensions of the native bony anatomy.[14,22,27] The anatomic shoulder prosthesis has undergone design improvements as successive studies have shown new information about the bony anatomy of the shoulder in detail.[3,14] This is needed in order to restore normal joint kinematics. Furthermore, the reverse shoulder prosthesis has a glenoid baseplate that has been designed to be seated and supported by the native glenoid bone.[10] The sizing options of the humeral prosthetic head and glenoid polyethylene in anatomic shoulder prosthesis and glenoid base plate in reverse shoulder systems have been developed after extensive morphologic studies of the native humeral head and glenoid.[9,14,15,17,28] However, a mismatch of size as small as 5 mm between the native humeral head and humeral head anatomic prosthesis may alter the joint excursion and range of

This study was approved by the institutional ethics committee of Dr. R.N. Cooper Hospital, Mumbai.

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motion.[12] Chinese, Japanese, and other Asian authors state that the Asian and Caucasian shoulder bones differ in several morphologic dimensions.[24,32,33] Because most of the designs of shoulder prostheses have been optimized for Caucasian bony geometry, some of the existing prosthetic systems may not match the morphology and sizes of the Asian population. A mismatch between the Indian native geometry and shoulder prosthetic sizing is also highly possible, because a mismatch of Indian knees with the femoral implants of knee replacement has been well documented.[18,31] Whereas there are several reports from the East Asian population,[1,23,24,33] there are limited reports of differences between the Indian and the Caucasian bones in the shoulder. Therefore, our aim was to study the geometry of the proximal humerus and glenoid and compare it with the current prosthesis and determine if there is any mismatch. Because our earlier cadaveric research had shown that some dimensions of the coracoid in Indians were consistently smaller than that in the Caucasian population,[30] we hypothesized that some of the morphometric dimension of the humeral head and glenoid in Indian population would be smaller than that of the Caucasian population.

Material and methods

Fifty patients (39 from Central and North India, 10 from South India, and 1 from West Bengal) who underwent computed tomographic (CT) scans of the pathologic shoulder for various fractures of the proximal humerus, fractures of the glenoid, and imaging for postoperative evaluations of the above fracture conditions were also scanned for their contralateral normal shoulder. The normal shoulders were scanned till the elbow, were free from osteoarthritis, and did not have a history of any other pathologies. The study population had 38 males and 12 females, and the average age was 37.8 years (range, 21-70 years).

CT scans

The imaging was performed on a 128-slice 1.5 Tesla Phillips CT scan machine with 1 mm slices in 0.5 mm increment osseous windows.

The images were obtained in Digital Imaging and Communication in Medicine format. These images were then transferred to HOROS, which is an open-source image viewing platform based on OsiriX. All the measurements were performed in HOROS software in 2-dimensional images. Three planar reconstructions of the Digital Imaging and Communication in Medicine bone thin images were performed to obtain 2-dimensional images in the sagittal, axial, and coronal section.

Humeral head

We measured the following parameters of the humeral head: superoinferior (SI) diameter of the humeral head, anteroposterior

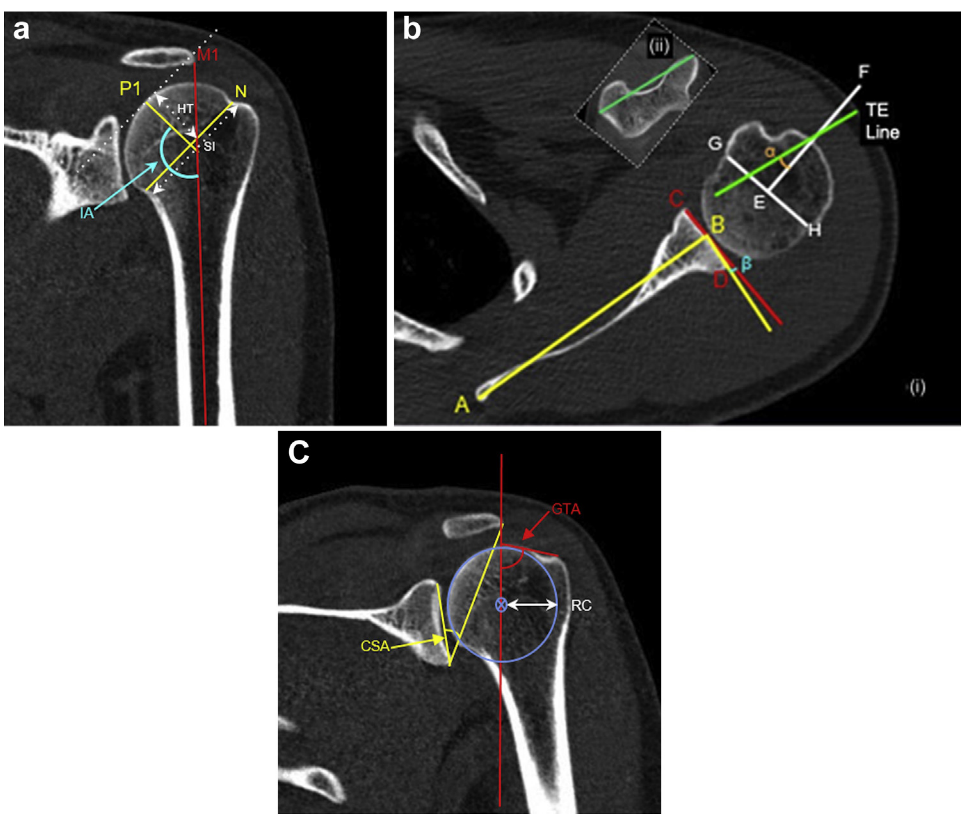

Figure 1 (**a**) Proximal humeral measurements: the thickness of the articular surface (HT) is the distance between the line along the anatomic neck (N) and the tangent to the surface of the humeral head that is parallel to line N (*white dotted line*). The inclination angle (IA) is defined as the angle between the head axis (P1) and the proximal humeral shaft axis in the coronal plane (M1). Superoinferior (SI) diameter was measured along the line N. (**b**) (i) Humeral retroversion angle (α) is the angular difference between the orientation of the proximal humeral head (EF) and the transepicondylar line (TE line) at the distal humerus (inset ii). Glenoid version angle (β) is defined as the angle between the glenoid line (CD) and the line perpendicular to the scapular axis (AB). (**c**) The radius of curvature (RC) is the radius of the circle best fitting the arc of the humeral head. The angle formed between the line connecting the superior to inferior margin of the glenoid and the line joining the inferior margin of the glenoid to the lateral most tip of the acromion was measured as the critical shoulder angle (CSA). Greater tuberosity angle (GTA) is defined as an angle formed by the line connecting the top of the humeral head to the highest point of greater tuberosity and another line parallel to the metaphyseal line that passes through the center of the circle of the humeral head curvature.

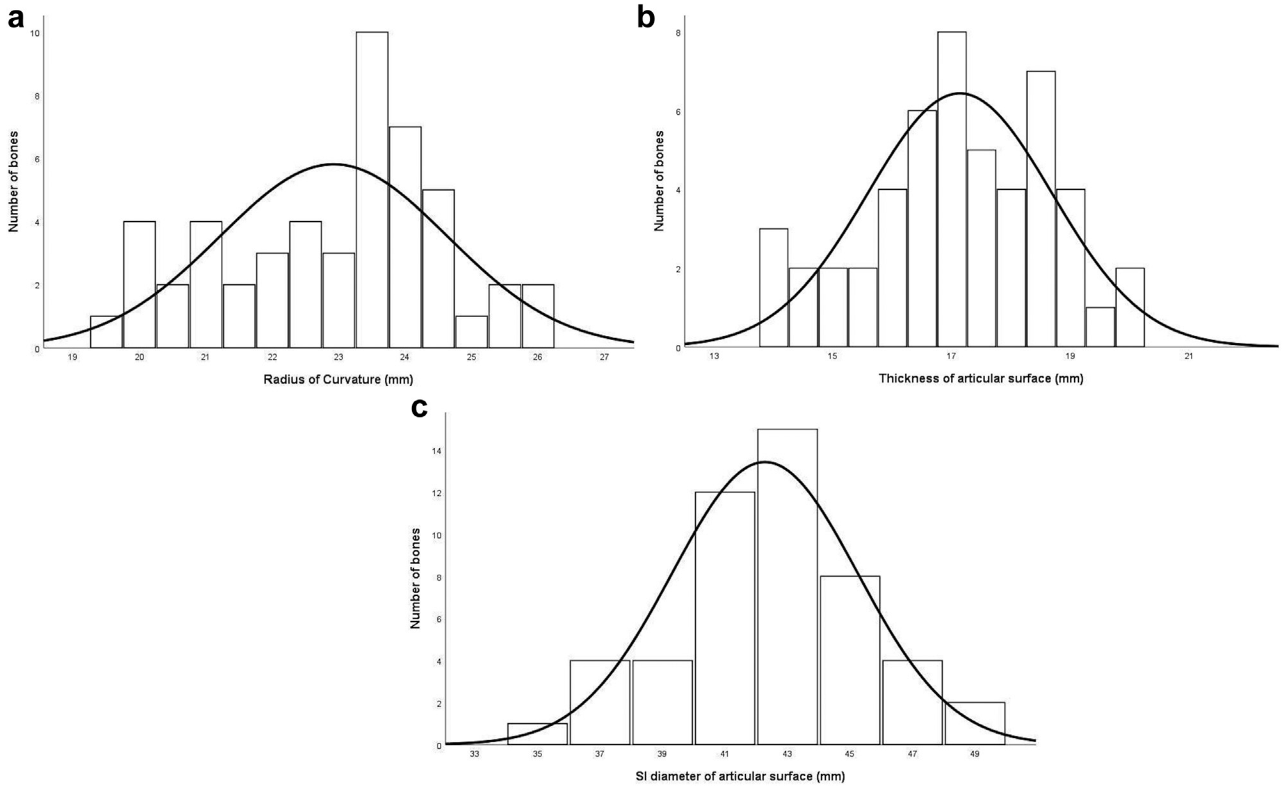

Figure 2 Distribution of the humeral head radius of curvature (**a**), thickness of the articular surface (**b**), and superoinferior (SI) diameter of the articular surface (**c**).

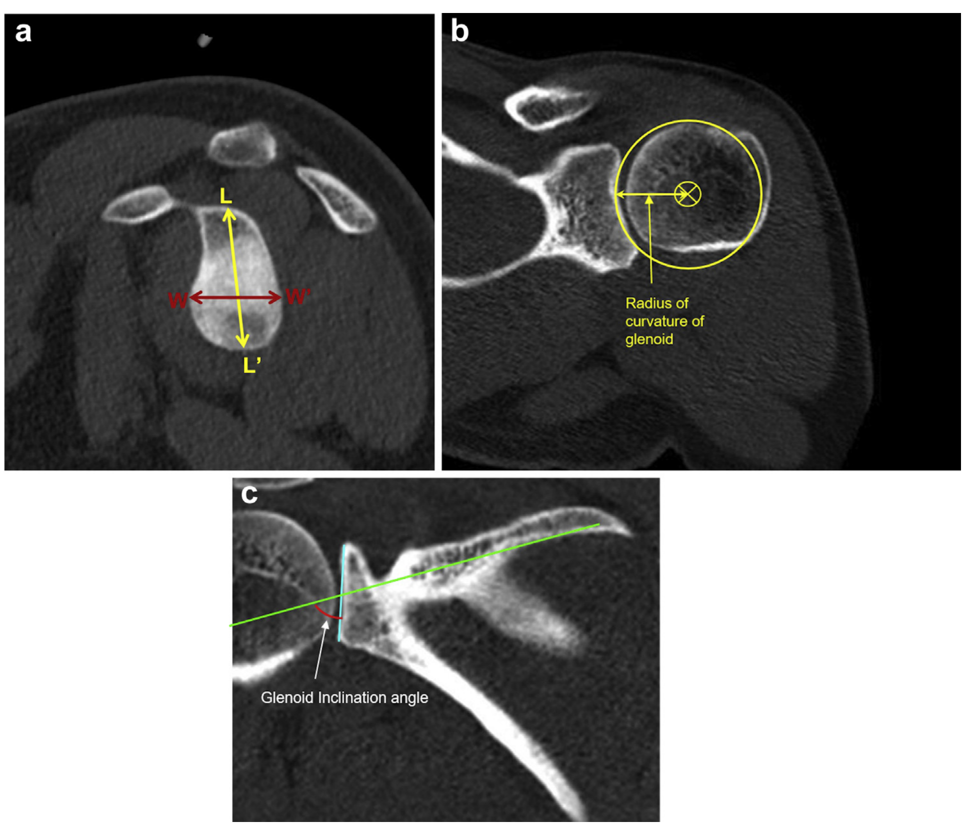

Figure 3 (**a**) The superoinferior length is the length of the line connecting points L and L′, which were the most superior and most inferior points on the glenoid, and the glenoid width is the length of the line joining the widest part of the glenoid (denoted by the line joining points W and W′). (**b**) The radius of curvature of the glenoid is the radius of the circle best fitting the arc of the glenoid cavity in the coronal plane. (**c**) Glenoid inclination angle is defined as an angle between the line connecting the cortical margin of the supraspinatus fossa (*green line*) and the line joining the superior glenoid rim and inferior glenoid rim (*blue line*).

(AP) diameter of the humeral head, radius of curvature of the humeral head in the coronal plane, humeral head retroversion, humeral head thickness, and inclination angle. In addition, we also calculated the critical shoulder angle (CSA) and greater tuberosity angle (GTA).

In the coronal section, we drew a line along the anatomic neck of the humeral head (Fig. 1, *a*). The limits of the anatomic neck were defined by the limits of the subchondral bone that are also the limits of the cartilage as defined by Laumann and Kramps.[20] The SI diameter was measured as the largest length of this line in the coronal section. The head axis was marked as the perpendicular line (P1), which was drawn from the neckline (N) to the center of the humeral head. Another line (M1) was drawn in the humeral shaft in the center of the metaphyseal cylinder as per Boileau and Walch.[3] P1 was extended to join M1, and the angle extended between the lines was the inclination angle. A circle was drawn that best approximated the humeral head curvature. The radius of the circle was called the radius of curvature of the humeral head. The transepicondylar line was drawn at the elbow by joining the medial and lateral epicondylar points (Fig. 1, *b*). This line was propagated till the section where the P1 of the humeral head was visible, and the angle subtended between these 2 lines was recorded as the version of the humeral head. On the sagittal section of the humeral head, the AP diameter was measured by drawing a line connecting the 2 widest points. The GTA was measured as per the technique of Cunningham et al[4] by drawing a line connecting the top of the humeral head to the highest point of greater tuberosity and another line parallel to the metaphyseal line, which passed through the center of the circle of the humeral head curvature (Fig. 2). The angle between these 2 lines was the GTA (Fig. 1, *c*). CSA was measured as described by Moor et al[26] (Fig. 1, *c*). The angle formed between the line connecting the superior to inferior margin of the glenoid and the line joining the inferior margin of the glenoid to the lateral most tip of the acromion was measured as the CSA.

Glenoid

Three planar reconstructions were performed for the glenoid separately. The glenoid width was measured between the 2 points on the widest part of the glenoid (Fig. 3, *a*). The SI length was measured along the line joining the most superior to the most inferior point on the glenoid. A circle was drawn that best approximated the curvature of the glenoid in the mid coronal plane. The radius of this circle was called the radius of curvature of the glenoid (Fig. 3, *b*). The retroversion of the glenoid was measured in the axial plane by the technique of Friedman et al[8] (Fig. 1, *b*). The inclination of the glenoid was measured as per beta angle of Maurer et al[25] (Fig. 3, *c*). A line was drawn along the cortical margin of the supraspinatus fossa. The second line was a line joining the superior and inferior points on the glenoid fossa. The angle formed between the above 2 lines on the humeral side was measured as the beta angle of inclination.

Standardization of the CT scan measurements

For all the humeral measurements, 3 plane formatted images were referenced to choose the desired slice. For the SI diameter measurements, the sagittal image was divided into 3 equal parts. The central third was sectioned in several 1 mm sliced images and the diameter was measured in all the corresponding coronal images. The measurement was performed on the basis of predecided landmarks (described above) in each of the sections. The final measurement was read from the slice that had the largest diameter and met the criterion of landmarks. Similarly, the AP diameter was read from the sagittal section by following the technique of having multiple 1 mm sections in the middle third and measuring from each of them. All other humeral head and glenoid parameters were measured following similar techniques of multiple slicing and then choosing the most precise value based on the best approximation, largest length, and confirmation of the landmarks.

Statistical analysis

The sample size was estimated using the study variables from the earlier studies.[23,24] The highest variance was observed for humeral head version among the study variables. Hence the sample size was calculated using the variance for humeral head version (13.7). The minimum sample size needed for 80% power and type 1 margin of error (MOE) of 5% was calculated to be 46 by the formula $n = Z^2_{\alpha/2} * p2/MOE2$, where p is the variance and $Z^2_{\alpha/2}$ is the critical value to the normal distribution at $\alpha/2$.

All data were represented as mean, standard deviation, and 80% range (10th and 90th percentile). We used bar graphs to show the distribution of various geometric parameters. An independent sample *t*-test was used to evaluate differences between males and females. We compared our results with those of the Japanese,[24] the Chinese,[33] and the Caucasian population by combining various cohorts from the literature.[3,5,14,19,27,29] Pearson's coefficient was used to find correlations between head thickness and SI diameter of the head, radius of curvature of the glenoid, and radius of curvature of the humeral head. Two independent observers at different time points measured the dimensions of the humeral head and glenoid cavity in the CT scan images of 20 randomly selected patients. These 20 paired measurements were used to calculate the intraclass correlation coefficient as a measure of the interobserver reliability. After determining the reliability, the final measurements were performed by 1 observer in all the 50 shoulder CT scan images.

Results

Dimensions of humeral head

The radius of curvature of the humeral head averaged 22.9 ± 1.7 mm (80% range, 20.3-24.7 mm) (Fig. 2, *a*), the articular surface thickness 17.1 ± 1.6 mm (80% range, 15-19 mm) (Fig. 2, *b*), the SI

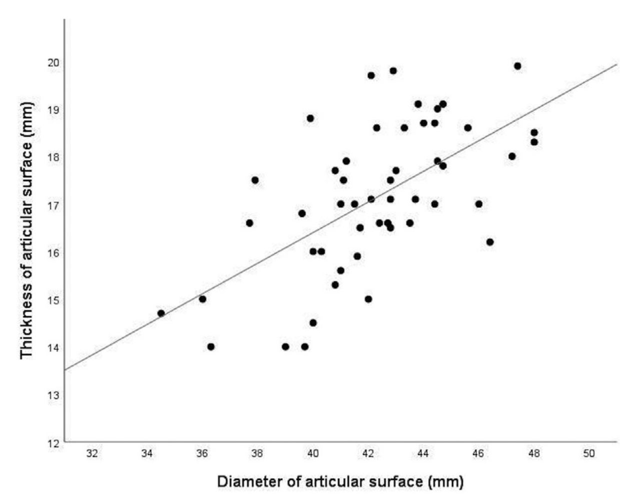

Figure 4 Scatterplot of the superoinferior diameter of the articular surface of the humerus vs. the thickness of the articular surface in our cohort. The best-fit linear regression line shows a strong correlation between the articular surface diameter and thickness.

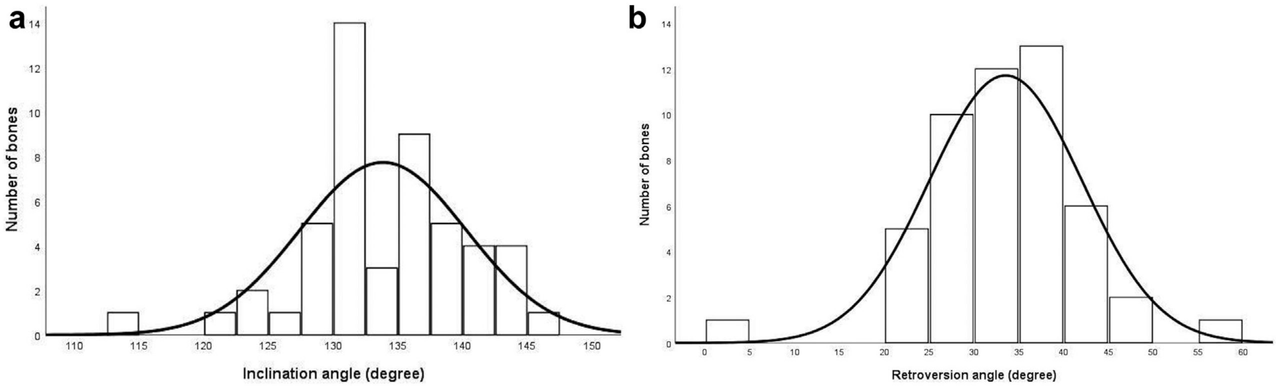

Figure 5 Distribution of the humeral head inclination angle (**a**) and retroversion angle (**b**).

diameter 42.3 ± 3 mm (80% range, 36.9-46 mm) (Fig. 2, *c*), and the AP diameter 40.1 ± 2.8 mm (80% range, 36.9-43.4 mm). SI diameter strongly correlated with thickness ($r = 0.617$, $P = .001$) (Fig. 4), with a linear regression relationship $3.53 + 0.32*x$. The inclination angle averaged 133.8° ± 6.4° (80% range, 127.5°-141.8°) (Fig. 5, *a*), and the retroversion angle averaged 33.5° ± 8.5° (80% range, 24.4°-44.3°) (Fig. 5, *b*) (Table I).

Dimensions of glenoid cavity and glenohumeral conformity

The values for the glenoid cavity averaged 23.3 ± 3.4 mm (80% range, 19.3-28 mm) for the radius of curvature (Fig. 6, *a*), 24.0 ± 2 mm (80% range, 21.6-26.4 mm) for the glenoid width (Fig. 6, *b*), and 31.3 ± 2.2 mm (80% range, 28.5-33.9 mm) for the SI length (Fig. 6, *c*). The intraclass correlation coefficient values for each measurement are noted alongside in Table I (Table I; Fig. 6, *a*-e).

Differences according to sex

Women had a significantly smaller humeral head (radius of head curvature, thickness, SI, and AP diameter) and glenoid dimensions (glenoid width and SI length) than men (Table II).

Comparison with other populations

Humeral head dimensions

The average retroversion of the humeral head in our study (33.5°) was significantly larger than that reported in the Chinese cohort by Zhang et al[33] (22.6°, $P < .0001$) and also significantly larger than that reported in the Western cohort (22.2°, $P < .0001$) derived by combining the ones in the studies by Boileau et al,[3] Kronberg et al,[19] Harrold et al,[11] Hernigou et al,[13] and DeLude et al.[5] The average humeral head radius of curvature in our study (22.9 mm) was significantly larger than that reported in the study by Zhang et al[33] (22.1 mm, $P = .01$) and that in the Japanese cohort by Matsumura et al[24] (21.4, $P < .001$) but significantly smaller than that in the Western cohort[3,5,14,27,29] (23.6 mm, $P < .05$). The average SI articular surface diameter in our study (42.3 mm) was significantly smaller than that of the Western cohorts (44.5 mm, $P = .001$), which was reported by only Boileau and Walch[3] and Hertel et al,[14] but was similar to that of the Chinese cohort (42.9 mm, $P = .32$) and to that of the Japanese cohort (41.4 mm, $P = .11$), as reported by Zhang et al and Matsumura et al, respectively. The inclination angle in our cohort (133°) was smaller to that in the Western cohort (136°, $P = .003$) but similar to that in the study by Zhang et al (133.8°, $P = .34$) (Table III).

Table I
Geometric measurements of the humeral head and glenoid cavity

Parameter	Mean ± SD	Minimum	Maximum	10th percentile	90th percentile	ICC (95% CI)
Humeral head						
Radius of curvature (mm)	22.9 ± 1.7	19.5	25.9	20.3	24.7	0.956 (0.889-0.983)
Articular surface thickness (mm)	17.1 ± 1.6	14.0	19.9	15.0	19.0	0.991 (0.978-0.997)
SI diameter (mm)	42.3 ± 3.0	34.5	48.0	36.9	46.0	0.829 (0.564-0.932)
AP diameter (mm)	40.1 ± 2.8	33	45.9	36.9	43.4	0.798 (0.482-0.920)
AP/SI articular surface diameter ratio	0.9 ± 0.9	1.0	1.0	0.9	0.9	
Articular surface thickness/radius of curvature ratio	0.7 ± 0.9	0.7	0.8	0.7	0.8	
Inclination angle (°)	133.8 ± 6.4	113.3	147.2	127.5	141.8	0.801 (0.494-0.921)
Retroversion angle (°)	33.5 ± 8.5	4.0	57.1	24.4	44.3	0.958 (0.895-0.983)
GTA (°)	67.8 ± 3.1	61.3	74.5	63.9	71.6	0.793 (0.469-0.919)
Glenoid cavity						
Glenoid width (mm)	24.0 ± 2.0	20.4	28.6	21.6	26.4	0.858 (0.646-0.943)
Glenoid SI length (mm)	31.3 ± 2.2	27.4	36.5	28.5	33.9	0.784 (0.458-0.914)
Glenoid retroversion (°)	1.8 ± 3.8	8.8	−11.7	7.2	−2.0	0.975 (0.975-0.990)
Radius of curvature of glenoid (mm)	23.3 ± 3.4	15.8	29.9	19.3	28.0	0.888 (0.715-0.956)
CSA (°)	34.5 ± 4.2	43.1	25.3	29.6	39.7	0.607 (0.016-0.846)
Glenoid inclination (°)	78.7± 4.8	70.7	95.9	73.0	84.3	0.918 (0.795-0.986)
Radius of curvature/radius of curvature of glenoid ratio	1 ± 0.5	1.2	0.9	1.0	0.9	

SI, superoinferior; *AP*, anteroposterior; *GTA*, greater tuberosity angle; *CSA*, critical shoulder angle; *SD*, standard deviation; *ICC*, intraclass correlation coefficient; *CI*, confidence interval.

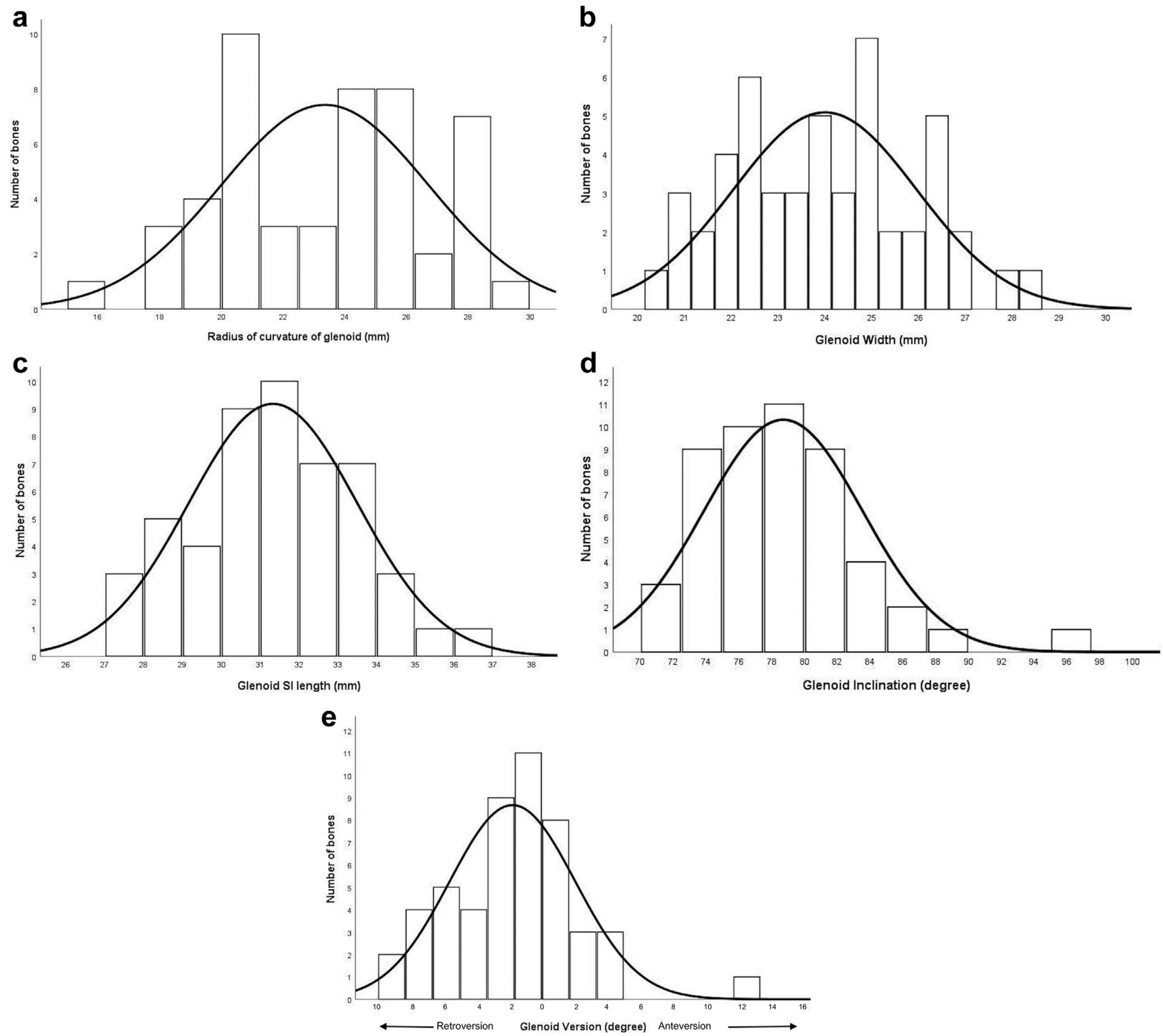

Figure 6 Distribution of glenoid cavity: radius of curvature of the glenoid (**a**), glenoid width (**b**), glenoid superoinferior (SI) length (**c**), glenoid inclination (**d**), and glenoid version (**e**).

Glenoid dimensions

The glenoid SI length and width (31.3 mm, 24.0 mm) in our cohort were significantly smaller than those in the Western cohort (39.0 mm, $P < .0001$; 29.0 mm, $P < .0001$), as reported by Zumstein et al[34] and Iannotti et al,[16] but larger than those in the Chinese cohort (30.15 mm, $P = .049$; 20.35, $P < .0001$). The glenoid radius of curvature in our study (23.3 mm) was significantly smaller than that of the Western cohort[34] (28.2 mm, $P < .05$) but similar to that of the Chinese cohort by Zhang et al (23.49 mm, $P = .71$) (Table IV).

Comparison of humeral head dimensions with the current prostheses

We compared the articular surface thickness and diameter in our study with the dimensions of some currently available shoulder implants in India. The regression line of this study cohort and 95% confidence lines are included in the graph. The prosthetic systems that were added included DePuy Global Advantage, Evolutis, Exactech Equinoxe, Biomet Comprehensive, and Stryker ReUnion (Fig. 7).

Only Exactech, Equinoxe, and Biomet Comprehensive prostheses had sizes of 38 mm available, whereas 16% of our subjects had an articular surface diameter of less than 40 mm. Size combinations of Exactech were according to the slope of our graph but with half of the thickness options were out of the 95% confidence interval line. The smaller diameter implants of Biomet had combinations with a bigger thickness of the humeral head, where smaller options may be needed according to our graph. DePuy, Evolutis, and Stryker had implant sizes starting from 40 mm. Humeral head diameters of DePuy's Global advantage were available in increments of 4 mm with large thickness at lower diameters. Stryker thickness was also large for a given diameter except at 44 mm diameter and it was in 4 mm increments. Evolutis had only 5 fixed combinations only with 3 mm increments in humeral head diameter.

Table II
Sex differences in geometric measurements

Parameter	Mean ± SD		*P* value
	Male	Female	
Humeral head			
Radius of curvature (mm)	23.6 ± 1.3	20.8 ± 0.9	<.001*
Thickness of articular surface (mm)	17.4 ± 1.4	16.0 ± 1.5	.003
SI diameter (mm)	43.3 ± 2.2	38.7 ± 2.3	<.001*
AP diameter (mm)	41.2 ± 1.9	36.7 ± 2.4	<.001*
AP/SI articular surface diameter ratio	0.9 ± 0.06	0.9 ± 0.05	.492
Thickness of articular surface/Radius of coronal curvature ratio	0.7 ± 0.08	0.8 ± 0.05	.057
GTA (°)	67.8 ± 3.3	67.9 ± 2.4	.921
Inclination angle (°)	133.3 ± 6.7	135.4 ± 5.5	.344
Retroversion angle (°)	33.4 ± 9.2	33.9 ± 6.4	.861
Glenoid cavity			
Glenoid width (mm)	24.5 ± 1.9	22.5 ± 1.5	.001*
Glenoid SI length (mm)	31.8 ± 2.1	29.9 ± 1.9	.007
Glenoid retroversion (°)	2.5 ± 3.4	−0.5 ± 4.3	.14
CSA (°)	34.1 ± 4.1	35.5 ± 4.5	.331
Glenoid inclination (°)	77.8 ± 4.2	81.5 ± 5.9	.2
Radius of curvature of glenoid (mm)	23.5 ± 3.5	22.6 ± 2.7	.39

SI, superoinferior; *AP*, anteroposterior; *GTA*, greater tuberosity angle; *CSA*, critical shoulder angle; *SD*, standard deviation.
* Indicates *P* values are statistically significant.

Comparison of glenoid dimensions with the glenoid base plate of reverse shoulder replacement

The available glenoid baseplate sizes for the reverse shoulder systems are 29 mm and 25 mm. None of the subjects in our cohort had glenoid width more than 29 mm. In 32% of the subjects, the glenoid width measured between 25 mm and 29 mm, and in 68% of the subjects, the glenoid width measured less than 25 mm (Fig. 8). The maximum glenoid width in the females was 25 mm in our cohort.

Discussion

Prosthetic mismatch with the native anatomy during anatomic shoulder arthroplasty can affect the joint kinematics and the final outcomes.[12] In the reverse shoulder replacement, the glenoid base plate needs to be adequately supported by the bone of the glenoid vault. We already know that the Indian and the Caucasians bones of the knee joint may differ in their anatomic dimensions.[31] Because we did not find any study on the geometric measurements of the shoulder in the Indian population that could guide us in decision

Table III
Comparison of humeral head dimensions among studies

Parameter/Population	Previous studies		Current study (Indian cohort)		*P* value*
	Mean ± SD	Sample size	Mean ± SD	Sample size	
Radius of curvature (mm)			22.9 ± 1.7	50	
Western[3,5,14,27,29]	23.6 ± 2.4	374			.05
Chinese[33]	22.1 ± 1.9	80			.02
Japanese[24]	21.4 ± 1.8	160			<.001*
Articular surface thickness (mm)			17.1 ± 1.6	50	
Western[3,5,14,27,29]	16.9 ± 2.1	374			.52
Chinese[33]	16.9 ± 1.5	80			.47
Japanese[24]	13.2 ± 1.7	160			<.001*
SI diameter (mm)			42.3 ± 3	50	
Western[3,14]	44.2 ± 4.1	265			.001*
Chinese[33]	42.9 ± 3.6	80			.33
Japanese[24]	42.9 ± 3.6	160			.29
AP/SI articular surface diameter ratio			0.9 ± 0.9	50	
Western[16]	0.92	140			
Chinese[33]	0.93 ± 0.03	80			.77
Japanese					
Articular surface thickness/radius of curvature ratio			0.7 ± 0.9	50	
Western[14,27]	0.71 ± 0.05	221			.87
Chinese[33]	0.77 ± 0.05	80			.49
Japanese					
Inclination angle (°)			133.8 ± 6.4	50	
Western[3,5,14,27,29]	136 ± 4.7	374			.00
Chinese[33]	133 ± 3.1	80			.34
Japanese[24]	135 ± 3	160			.23
Retroversion angle (°)			33.51 ± 8.5	50	
Western[3,5,11,13,19]	24.5 ± 12.2	498			<.001*
Chinese[33]	22.6 ± 10.2	80			<.001*
Japanese[24]	32 ± 11	160			<.001*

SI, superoinferior; *AP*, anteroposterior; *SD*, standard deviation.
* Indicates *P* values are statistically significant.

Table IV
Comparison of glenoid cavity dimensions among studies

Parameter/Population	Previous studies		Current study (Indian cohort)		*P* value*
	Mean ± SD	Sample size	Mean ± SD	Sample size	
Glenoid width (mm)			24.0 ± 2	50	
Western[16]	29 ± 3.1	140			<.001*
Chinese[33]	20.35 ± 2.56	80			<.001*
Glenoid SI length (mm)			31.3 ± 2.2	50	
Western[16]	39 ± 3.7	140			<.001*
Chinese[33]	30.15 ± 3.70	80			.049
Radius of curvature of glenoid (mm)			23.3 ± 3.4	50	
Western[34]	28.2 ± 6.8	9			.001
Chinese[33]	23.49 ± 2.48	80			.713

SI, superoinferior; *SD*, standard deviation.
* Indicates *P* values are statistically significant.

making, our aim with this study was to describe the morphology in Indian bones and to evaluate the differences or similarities with the Caucasian and Chinese bones and compare it with the shoulder prosthetic systems available in India today.

We found that the humeral articular surface diameter and the radius of curvature in our cohort were significantly smaller and the retroversion angle significantly larger than those in the Western population. However, the thickness of the humeral head was not significantly different between them. Our diameters were closer to those of the Chinese and the Japanese population than those of the Western population. However, the ratio between the articular surface thickness and the radius of curvature in our study (0.7) was similar to that in the studies by Pearl and Volk[27] (0.73), Hertel et al[14] (0.71), and Zhang et al[33] (0.77). We found that there is a significant mismatch of the prosthetic head size and thickness combinations with the bone sizes of the Indian population. Because the ratio of radius of curvature to thickness remains the same, lower head diameters should be matched with lower thickness options. However, we found that almost all implant manufacturers had larger thickness combinations with lower diameter sizes. Our study also found that the glenoid width and length were significantly smaller than those of the Western population, although bigger than those of the Chinese cohort. Because 68% of the glenoid widths in our cohort were below 25 mm, the smallest base plate that is available (25 mm) may be big for the majority of our population. Moreover, none of the female glenoid widths in our cohort measured more than 25 mm. A 25-mm-sized base plate has been found to produce good outcomes and may be necessary in the female population.[2] Although it is not known how a mismatch of a few mm between a glenoid width and baseplate may affect the longevity, a bigger mismatch (>5 mm) in case of a glenoid width that is smaller than 20 mm could be potentially worrisome.[10,21] The glenoid radius of curvature in our cohort was also significantly smaller from that of the Western cohort. This difference will have implications in fitting the polyethylene to the native glenoid.

As with other population studies, the humeral diameter, radius of curvature, thickness, and glenoid width and length were significantly smaller in the females than in the males.[24,33] Thus, smaller implant options will be needed while operating on a female patient.

The findings of our study should be helpful in decision making for the surgeons and also for the implant manufacturers. The implant manufacturers should be aware of the minimum size that should be available within the inventory as well as the thickness combinations that will go with it. Our study also found that, of the available systems available in India, only Exactech and Biomet implant systems had sizes of humeral heads below 40 mm, but even in them, the thickness combinations were bigger for our population. A 4 mm jump in successive sizes like that of DePuy or Stryker may make their use difficult, because 58% of our cohort lay between 40 and 44 mm. Furthermore, we may need more options of humeral head sizes between 37 and 46 mm, because 80% of our cohort's means lay within that interval. This mismatch is significant because if it displaces the center of rotation by 20%, it may alter the lever arm of the rotator cuff by 20%.[12]

On comparing our results with the studies that used the transepicondylar line as the reference line to measure the retroversion of

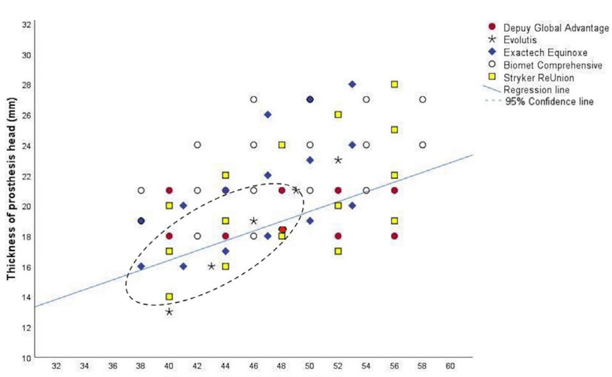

Figure 7 Comparison of the diameter and thickness of the humeral articular surface in our cohort with the dimensions (head size and thickness) of different shoulder prostheses. A regression line and a 95% confidence ellipse of the study cohort are plotted with humeral heads of DePuy Global Advantage, Evolutis, Exactech Equinoxe, Biomet Comprehensive, and Stryker ReUnion.

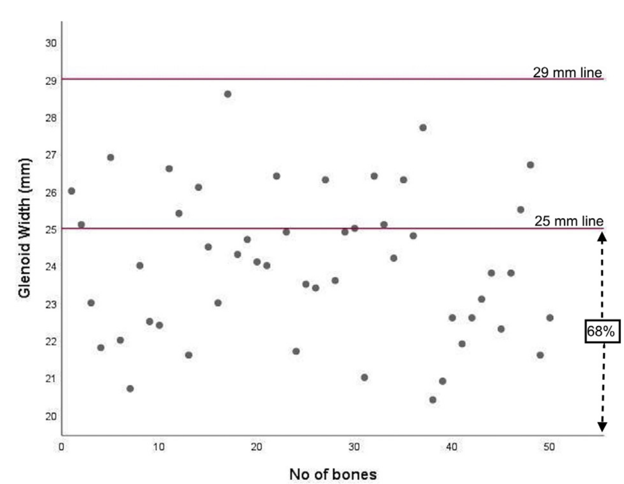

Figure 8 Distribution of glenoid width measurements in our cohort plotted against the glenoid base plate sizes (25 mm and 29 mm).

the humeral head, we found that the retroversion in our cohort was significantly larger than that in both the Western and the Chinese cohort. The retroversion of the humeral head has been found to vary between different ethnic groups, and our results could just represent an ethnic variation.[6]

The glenohumeral mismatch was 0.4 in our study, 1.45 in the study by Zhang et al,[33] whereas it was 2.3 in the study by Iannotti et al.[16] The inclination angle of the humeral head in our population was also smaller than that in the Western cohort. This angle should be kept in mind while using fixed angle systems of anatomic prosthesis, which adapt the bone cuts to the prosthesis. Hence the manufacturer's recommendation should be followed rather than making free-hand cuts of the anatomic neck.

The main limitation of our study was that in order to establish the means of the Caucasian population, we combined the results of other Western studies though they may have adopted different methodologies for measurements and calculations. We also did not correlate the variables with the height of the individuals in our study. We did not perform an arthrogram along with the CT scan, though an arthrogram may give better delineation of the cartilage. However, because the thickness of the humeral head cartilage has been reported to be an average of 0.89 mm, this should not make a large difference in the measurements.[7] Moreover, many studies have measured the parameters on CT scans without including the cartilage width.[14,23,24,27,32] Lastly, although our sample size (n = 50) was precalculated based on variables from other Asian studies, a larger sample may provide more information on the shoulder geometry. Future studies may need morphometric studies with interethnic comparison between the different ethnic groups of India.

Conclusion

The humeral head diameter and radius of curvature were significantly smaller than those of the Western population and similar to those of the Chinese cohort. The glenoid length and width in our cohort were also significantly smaller than those of the Caucasian population. However, the current humeral head sizes and thickness combinations of the anatomic prosthesis and glenoid baseplate size of the reverse shoulder prosthesis are big for our population. Hence, smaller size options of the humeral head and glenoid may be needed that suit our population and avoid a size mismatch.

Disclaimer

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