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3D CT scan-based study of glenoid morphology in Indian population: Clinical relevance in design of reverse total shoulder arthroplasty☆

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ABSTRACT

Background: The knowledge of normal anatomy of glenoid in a population has relevance in terms of comparison with other regional and national population. Furthermore, it could enable clinicians to judge whether the available sizes of reverse total shoulder arthroplasty (RTSA) prosthesis could provide optimal fit for the glenoid in Indian patients.
Methods: We evaluated consecutive 200 3-dimensional chest CT scans of 50 male and 50 female patients which included both shoulder joints and done for non-orthopaedic diseases at a tertiary care institute. The glenoid height, width, and version were measured using commercially available computer program.
Results: Mean age of the patents was 38.6 ± 13.8 years (range, 19–59 years). The mean glenoid height was 33.9 ± 3.1 mm and maximum glenoid width was 24.2 ± 2.1 mm. Mean glenoid version in the study population was a retroversion of 3.47 ± 4.7°. The maximum glenoid width of 45% female and 15% male patients was less than 25 mm which is the diameter of smallest available glenoid baseplate among the commonly used RTSA systems.
Conclusions: The normal glenoid size of a large cohort of Indian population studied was smaller than that reported in cohorts from western countries. The glenoid width of substantial proportion of patients, especially female patients, was less than the diameter of smallest available glenoid baseplate. Clinical studies are needed in future in Indian patients undergoing RTSA to evaluate the glenoid bone-baseplate mismatch and ascertain the necessity of development of smaller size glenoid baseplate for optimal prosthesis fit in Indian patients.

1. Introduction

The number of reverse total shoulder arthroplasty (RTSA) procedures performed has been increasing around the world including the Asian subcontinent.[2,3] The commonly used RTSA prostheses are made in western countries with reference from anatomical measurements in regional population.[4] It is unclear whether these RTSA prostheses provide optimal fit for relatively smaller glenoid size of Asian patients.[5] One of the reasons for this concern arises from the experience in the past with total knee arthroplasty prostheses. The previous studies related to regional variation in normal knee morphology of Asian population as compared to the population of western countries have led to modifications in design and sizes in the available knee prosthesis to facilitate better fit in Asian patients.[6,7] This regional variation has also led to the development of indigenous total knee arthroplasty prosthesis in India.[8] Hence, the knowledge of normal glenoid morphology of Indian population is essential to ascertain whether RTSA prosthesis designed to fit western population could provide optimal fit for Indian patients.

The glenoid width is the limiting dimension when choosing the glenoid baseplate size during RTSA surgery as the width of the glenoid cavity is always less than its height. There is a specific concern among orthopaedic surgeons whether the smallest available glenoid baseplate among commonly used RTSA prostheses is too big for relatively smaller glenoid width of Asian

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population.[5,9,41,42] A mismatch between glenoid width and baseplate diameter leads to inadequate bone coverage of the baseplate. This could result in suboptimal bone ingrowth of baseplate predisposing to inadequate fixation and early baseplate loosening.[10] Hence, there has been an interest in studies reporting the glenoid morphology especially in terms of maximum glenoid width in Asian population in addition to those comparing its variation with Caucasian population.[5,12] The previous studies have reported glenoid morphological measurements in Indian population in northen,[13,14] southern,[15,16] eastern,[17,18] and western[19] regions of the country. However, these studies had major limitations as they were either done in cadavers, had limited sample size, or lacked clarity in clinical implications in terms of RTSA.

Previous studies have emphasized the placement of glenoid prosthesis in a retroversion of 15° or less during RTSA for favorable functional outcomes and prosthesis survival.[20–22] Hence, the knowledge of normal glenoid version and its variation in the regional population may be a guide for orthopaedic surgeons to ascertain acceptable glenoid version. However, as per our knowledge, none of the previous studies have reported normal glenoid version in a cohort of Indian population.

The aims of this study were two fold; 1. To report the glenoid height, width, and version in a large cohort of Indian population using computerized measurement on 3-dimensional computer tomography (3D CT) scans and 2. To compare these glenoid measurements with those reported in the literature in other cohorts of Indian, East Asian, and Caucasian population to determine if the regional variation is clinically relevant in terms of optimal fit with available RTSA prostheses.

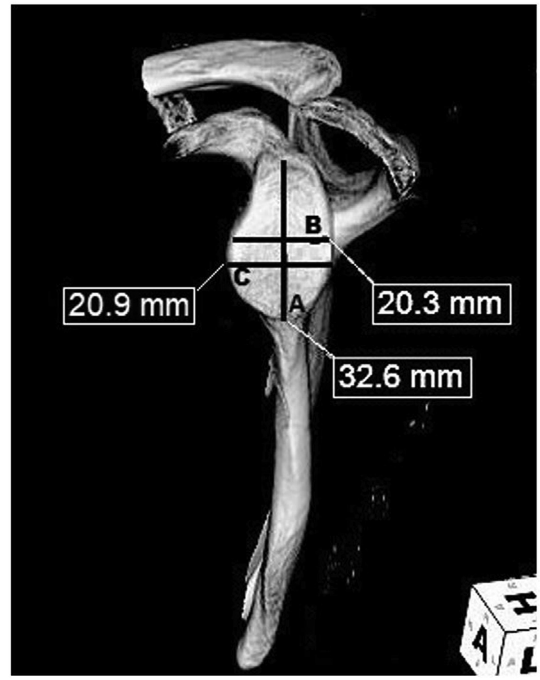

Fig. 1. The method of glenoid articular surface diameter measurements. Line A: Vertical linear measurement drawn on glenoid face to evaluate maximum glenoid height, line B: a second linear measurement drawn perpendicular to the line A and at its midpoint to evaluate the mid-glenoid width, and line C: third linear measurement drawn perpendicular to line A at the maximum anteroposterior glenoid diameter.

2. Methods

This was a cross sectional analysis of patient records of consecutive fifty male and fifty female patients who had chest CT scans which included bilateral shoulder for non-orthopaedic problems between Oct 2016 to June 2017 at a tertiary care center. The patient records which mentioned a history of shoulder symptoms or diseases were excluded. Additionally, shoulder CT scan images which showed arthritic changes in the form of reduced joint space and osteophytes or features of cuff tear arthropathy like superior migration of humeral head, superior glenoid erosion, and acetabulization of the acromion were excluded from the study. The patient consent was waivered.

200 3D CT images of bilateral shoulder joints were reconstructed from high-resolution CT scans using a commercially available computer program (Aquarius iNtuition, TeraRecon, Durham, USA). This computer application allows measurement of distance and angle between anatomic landmarks. It also allows 3D CT model and measuring tools to be freely shifted and rotated in different planes and axes along with image subtraction tool which enables precise glenoid measurements.

The outcome variables noted were glenoid height, mid-glenoid width, maximum glenoid width, and glenoid version. A vertical linear measurement was made on the glenoid bone articular surface to note the maximum supero-inferior diameter which was noted as glenoid height (Fig. 1 line A). Another linear measurement was made by drawing a line perpendicular to line A at its midpoint to note the mid-glenoid width (Fig. 1. Line B). A third line was drawn perpendicular to line A to measure the maximum glenoid anteroposterior diameter which was noted as maximum glenoid width (Fig. 1, line C).

The measurement of glenoid version using 3D CT scan was done using a previously described method by Hoenecke et al.[23] A 1 mm thin CT slice was generated along the transverse plane passing through the axis of center of glenoid and scapular spine (represented by line B in Fig. 1) using subtraction tool of the CT computer application. This transverse slice was then rotated and looked upon from superior surface (Fig. 2). First axis was drawn joining the most posterior to most anterior points of the glenoid rim which represented the angulation of glenoid with respect to transverse scapular plane (Fig. 2, line A). Another line was drawn between medial tip of scapula spine and midpoint of anterior and posterior rim of glenoid representing the transverse scapular axis (Fig. 2, line B). Second axis was drawn perpendicular drawn to line B (Fig. 2, line C). The glenoid version (Fig. 2, angle δ) was measured as

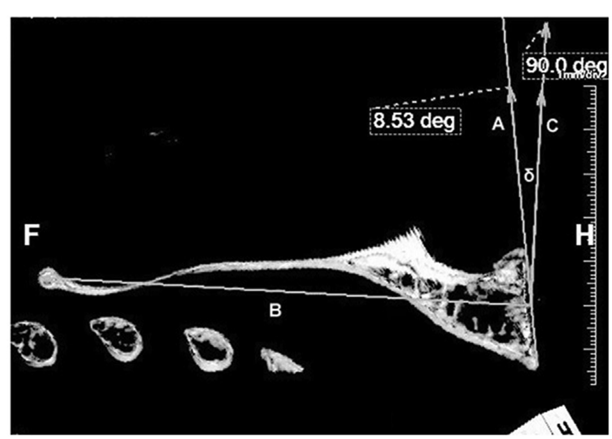

Fig. 2. The method of glenoid version measurement. Line A: Axis drawn joining the most posterior and anterior points of the glenoid rim, line B: axis drawn between medial tip of the scapular spine and midpoint of anterior and posterior rim of glenoid, line C is drawn perpendicular to line B, and δ is the glenoid version measure as the angle between line A and line C which is the inclination of the face of the glenoid in relation to transverse scapular axis that is line B.

the angle between line A and line C representing the inclination of the face of the glenoid at the level of the defined transverse plane. The glenoid retroversion was indicated by a negative sign before the angular measurement value whereas a positive sign was used to indicate glenoid anteversion. All measurements were performed by two sports fellowship trained orthopaedic surgeons (PM and AP) and noted after reaching consensus.

Among the most commonly used RTSA systems, the smallest available size of glenoid baseplate has a diameter of 25 mm for Aequalis Perform Reversed and Aequalis Reversed II system (Wright, Memphis, USA), 26 mm for Reverse Shoulder Prosthesis system (DJO Surgical, Austin, USA), 27 mm for the Delta Xtend system (DePuy Synthes, Warsaw, USA), 28 mm for ReUnion system (Stryker, New Jersey, USA), and 28 mm for Trabecular Metal Reverse Shoulder System (Zimmer, Warsaw, IN, USA). Hence, the smallest available glenoid baseplate among the commonly used RTSA systems has a diameter of 25 mm.[9] Accordingly, we noted the proportion of study patients with maximum glenoid AP diameter less than 25 mm as even the smallest available glenoid baseplate would be too big for the glenoid of these patients indicating glenoid bone-baseplate mismatch.

The statistical analysis was done using SPSS software version 22. The continuous variables were expressed in term of mean, standard deviation and range. Paired *t*-test was used to compare the findings between male and female patients. The p-values of < 0.05 were considered significant.

3. Results

The mean age of patents in the study was 38.6 ± 13.8 years (range, 19 − 59 years). The age of male and female patients was similar (39.3 ± 14.4 years versus 37.9 ± 13.3 years, p = 0.3). The mean glenoid height was 33.9 ± 3.1 mm, mid-glenoid width was 22.4 ± 2.4 mm, and maximum glenoid width was 24.2 ± 2.1 mm (Table 1). The glenoid measurements of male patients in terms of height (36.1 ± 2.4 mm versus 31.7 ± 1.9 mm, p = 0.0001), mid-glenoid width (23.9 ± 1.8 mm versus 20.9 ± 1.9 mm, p = 0.0001), and maximum glenoid width (25.8 ± 1.7 mm versus 22.6 ± 1.9 mm, p = 0.005) were more than those of female patients.

The proportion of patients with maximum glenoid width less than 25 mm was 30% (60 of total 200 patients). This proportion for female patients was 45% (45 of 100 female patients) whereas for the male subjects was 15% (15 of 100 male patients). The mean glenoid version in the study population was a retroversion of 3.47 ± 4.7° with a wide variation (range, retroversion of 12° to anteversion of 8.4°) without a difference between male and female patients (Table 1).

4. Discussion

There is a lack of studies in the current literature reporting the normal glenoid morphological measurements in living human subjects in a cohort from Indian population. As per our knowledge, this is the first study in the literature to report 3D CT scan based normal glenoid measurements including version in a relatively large sample size of Indian population. A wide variation was found in glenoid height, maximum width, and version. The maximum glenoid width of substantial proportion of female (45%) and male (15%) subjects of the study was less than the diameter of smallest available size glenoid baseplate among commonly used RTSA systems.

While previous studies have reported normal glenoid morphological measurements in Indian population, they were done on dried cadaveric specimens.[13–19] Additionally, the demographic characteristics and history of shoulder disease were not reported in the previous studies which makes it difficult to confirm whether the cadavers belonged to a cohort who had no shoulder pathology. In contrast, the glenoid measurements in our study were done in living human subjects which more closely depicts the usual clinical scenario. Moreover, the patients included in this series had no history or radiological evidence of shoulder disease which makes them a suitable homogenous cohort to study normal glenoid morphology. Additionally, an advanced technique of CT scan based glenoid measurement was employed which is routinely used as a diagnostic and surgical planning tool for shoulder arthroplasty.[24] Furthermore, we used 3D CT scan technology for the measurements which is argued to be better than 2D CT scans especially to evaluate glenoid morphology and version.[23,25,26] Hence, conducting the study in living subjects with no shoulder disease and employing advanced and proven imaging technology for measurements probably gives more credibility to the findings of current study as compared to the previous reports.

Table 1
Glenoid measurements in study population.

Glenoid Measurement	All shoulders (n = 200)	Shoulders of male patients (n = 100)	Shoulders of female patients (n = 100)	P-value
Glenoid height (mm)	33.9 ± 3.1 (28.1 − 39.9)	36.1 ± 2.4 (29.9 − 39.9)	31.7 ± 1.9 (28.1 − 35.6)	0.0001
Mid glenoid width (mm)	22.4 ± 2.4 (17.6 − 27.0)	23.9 ± 1.8 (19.9 − 27.0)	20.9 ± 1.9 (17.6–25.7)	0.0001
Maximum glenoid width (mm)	24.2 ± 2.1 (19.3 − 28.2)	25.8 ± 1.7 (20.1 − 28.2)	22.6 ± 1.9 (19.3–26.4)	0.0005
Glenoid version*	-3.5 ± 4.7° (−12° - +8.4°)	-4.1 ± 4.8° (−12° - +8.4)	-2.8 ± 4.2° (−10.6° - +7.43°)	0.096

* (−) denotes retroversion and (+) denotes anteversion.
All measurements are presented as mean ± standard deviation (range).

Table 2
Summary of glenoid height and maximum width measurements in Indian population belonging to different regions reported in previous studies.

Region of India	Study	No. of shoulders studied	Mean glenoid height (mm)	Mean maximum glenoid width (mm)
North	Singh et al.[13]	100	34.2	24.9
	Kohli et al.[14]	64	36.6	24.1
South	Uma et al.[15]	200	35.7	23.5
	Mamatha et al.[16]	202	33.8	23.2
East	Pal et al.[17]	110	33.9	23.5
	Akhtar et al.[18]	228	35.8	23.6
West	Ankushrao et al.[19]	107	36.8	24.5
	Meshram et al. (Current Study)	200	33.9	24.2

Indian population comprises vast diversity in terms of genes, race, and cultural traits reflected in the differences of anthropological and morphological characteristics of people from various regions.[27,28] Such differences may exist in the glenoid morphology among people from different parts of the country. However, the mean glenoid height and maximum glenoid width measurement in our study closely resemble the data reported in previous studies involving cohort from different regions of India[13–19] (Table 2). It must be noted that the mean maximum glenoid width has been reported in the range of 23–24 mm in these studies. Hence, similar to the results of current study, the mean glenoid width in Indian population from different regions of the country is consistently reported to be less than 25 mm which is the diameter of smallest available glenoid baseplate among commonly used RTSA systems.

The glenoid height and width of cohort in our study was lower than those reported in studies from non-Asian countries/continents such as Europe,[5,29,30] United States,[12,31–33] Australia,[33] Egypt,[34] and Nigeria[35] (Table 3). Furthermore, these measurements were either similar or smaller in our study population compared to glenoid height and maximum glenoid width reported in cohort belonging to other Asian countries like South Korea,[12,36] Japan,[5] and China.[37] We also reported the mid-glenoid diameter in our study population though we are unsure of its clinical significance. In terms of mean glenoid version, the mean values in our study cohort seem similar to those reported by morphological studies from western and other Asian countries.[5,29,31,37] We couldn't compare the variation in glenoid version among Indian population as none of the previous studies involving Indian population reported it. The finding of our study that the glenoid size measurements are more in male as compared to female subjects are consistent with previously published literature involving cohort from India as well as other countries.[12–19,26,29,31,32,34–37] Hence, the normal glenoid size of Indian population seems to be smaller than Caucasian population whereas glenoid version was comparable.

Another key finding of our study was that the maximum glenoid width of 45% female and 15% male patients of the study cohort was less than the diameter of smallest available glenoid baseplate among commonly used RTSA systems. This means that the placement of any of the commercially available glenoid baseplate of RTSA systems would result in glenoid bone-baseplate mismatch due to oversizing in 45% female and 15% male patients of our study. Wang et al. studied the morphology of arthritic shoulders in a cohort of Chinese patients and reported 41.7% of female and 5% of male patients have a maximum glenoid width of less than 25 mm.[37] This mismatch between RTSA baseplate and glenoid width can lead to inadequate bone coverage of baseplate leading to suboptimal fixation and increased risk of early prosthesis failure.[10,38] A biomechanical study suggested that a baseplate coverage of glenoid bone less than 50% leads to unstable prosthesis fixation even when a central screw is used with 4 peripheral locking screws.[39] Furthermore, pathologic glenoid bone loss seen in up to 40% of patients undergoing primary RTSA which may further increase the glenoid bone-baseplate mismatch leading to increased risk of baseplate loosening.[40] Hence, the findings of this study lead to the speculation that smaller glenoid size baseplate may be needed to reduce glenoid bone-baseplate mismatch for optimal prosthesis fit in Indian patients under going RTSA.

There are very few clinical studies in Asian population focused on impact of glenoid bone-baseplate mismatch in RTSA surgery due to relatively small glenoid size reporting intraoperative difficulties and postoperative functional outcomes and complications. Jha et al. studied the results of RTSA with a 28 mm baseplate diameter in a series of seven Japanese female patients.[41] The mean glenoid width in the patients was 23.9 mm which was less than the baseplate diameter of all available RTSA systems in their country at the time of the study. Due to posterior glenoid bone loss in patients, the surgeons had to place the baseplate anteriorly instead of the center of glenoid to avoid posterior cortical breach. This anterior placement of baseplate combined with glenoid bone-baseplate size mismatch due to small sized glenoid resulted in anterior overhang of baseplate in all the patients. The postopeartive functional outcomes or complications in the patients were not reported in all patients. Nonetheless, due to intraoperative glenoid bone-baseplate size mismatch, the authors recommended the need of smaller baseplates in Asian population. Ji et al. studied clinical outcomes in 42 Korean patients undergoing RTSA using a baseplate of diameter 29 mm.[42] They did not experience any intraoperative baseplate overhang or inadequate bone coverage, however, there was difficulty in insertion of glenoid baseplate and glenosphere in female patients with small glenoids. At mean follow up of two years, they found improvement in functional outcomes with no cases of baseplate failure. They concluded that the available glenoid baseplate and glenosphere prosthesis size were appropriate for the Korean patients of their study. They also conducted anatomical measurements in a different cohort of 92 normal shoulders of patients from the same region. This part of study showed that the mean diameter of inferior glenoid was 30.8 mm for female patients and 34.2 mm for male patients. The dimensions of glenoid in this study seem larger than the mean glenoid width of patients in our study and the study by Jha et al.[41] which explains the contrasting

Table 3
Summary of glenoid measurements reported in previous studies from different countries.

Study (Country)		No. of shoulders studied	Mean glenoid height (mm)	Mean maximum glenoid width (mm)	Glenoid version
Churchill et al.[31] (USA)		344	35.1	25.7	−1.2°
Iannotti et al.[32] (USA)		140	39	29	NR
Lombardo et al.[33]	(USA)	39	34.9	25.7	NR
	(Australia)	37	34.6	24.7	NR
Mathews et al.[29] (Switzerland)		18	36.6	27.8	−1°
Coskun et al.[30] (Turkey)		90	36.3	24.6	NR
Aigbogun et al.[35] (Nigeria)		200	36.9	25.3	NR
El-Din et al.[34] (Egypt)		240	38.9	28.2	NR
Mizuno et al.[5]	(France)	100	33.3	25.5	- 2.3°
	(Japan)	100	35.4	26.7	- 6°
Cabezas et al.[12]	(USA)	92	35.8	NR	NR
	(Korea)	58	33.4	NR	NR
Wang et al.[37] (China)		90	34.5	25.1	0°
Jung et al.[36] (Korea)		38	37.7	26.9	NR
Meshram et al. (India) Current Study		200	33.9	24.2	-3.5°

NR – not reported

results of no glenoid bone-baseplate mismatch found by Ji et al. We recommend future clinical studies in Indian paients undergoing RTSA to determine intraoperative glenoid bone-baseplate mismatch and its corelation with post operative functional outcomes and baseplate failure rate.

The findings of our study should be interpreted in view of several limitations. First, the sample size of our study was limited to extrapolate the results to diverse and large Indian population. However, we included a relatively large sample size than previous studies which could be considered as a representative sample of Indian population. Another limitation of this study is that the patient cohort had non-arthritic shoulders without bone loss or cuff tear arthropathy which is not the representative population of patients undergoing RTSA surgery. Hence, we are unable to comment if the proportion of patients with glenoid bone-prosthesis mismatch in this study will be similar in patients undergoing RTSA. Hence, future studies should evaluate the glenoid-baseplate mismatch in adequate sample size of patients undergoing RTSA. Nonetheless, this study can provide methodological guidance for such future studies. This study could also attract attention of researchers in India and Asia regarding the issue of glenoid bone-baseplate size mismatch and neccessity of development of smaller glenoid baseplate to facilitate optimal prosthesis fit in small sized glenoid of Asian patients.

5. Conclusion

The normal glenoid size of a large cohort of Indian population studied was smaller than that reported in the literature for Caucasian population. The glenoid width of substantial proportion of patients, especially female patients, was lower than the smallest baseplate of commercially available RTSA systems. Clinical studies are needed in future in Indian patients undergoing RTSA to evaluate the glenoid-baseplate mismatch and ascertain the necessity of development of smaller glenoid baseplate for optimal prosthesis fit in smaller size glenoid of Indian patients.

CRediT author statement

Prashant Meshram: Methodology, Data curation, Formal analysis, and Writing - Original Draft; **Aditya Pawaskar**: Resources, Methodology, and Formal analysis; **Aashay Kekatpure**: Conceptualization, Data curation, Supervision, Writing - Review & Editing, and Project administration.

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Declaration of competing interest

The contributing and corresponding authors have no conflicts of interest to disclose.

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