

Review Article

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Normative Glenoid Bone Mineral Density Values in a Non-Pathologic Adult Population: A Quantitative Computed Tomography Study with Age and Sex Stratification

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ABSTRACT

Objective: To establish age- and sex-specific normative computed tomography (CT) attenuation (Hounsfield unit, HU) reference values for the adult glenoid across cortical, subchondral, and trabecular regions, using opportunistic measurements from routine, non-dedicated thoracic CT, and to characterise their relationship with age and sex for preoperative shoulder arthroplasty planning.

Materials and Methods: In this prospective cross-sectional study, 106 adults (31 men, 75 women; age range 18–69 years, mean 43.5 ± 14.6 years) without clinical or imaging evidence of glenohumeral joint pathology underwent high-resolution CT of the thorax on a 128-slice scanner for unrelated indications. On coronal images through the glenoid cavity, five standardised 2.5-mm square regions of interest (ROIs) were placed: subchondral cortical bone (SC), two trabecular layers (T1, T2), and two cortical rim regions (CO1, CO2). Mean HU values were compared by sex (independent-samples t-test) and age group (one-way ANOVA with Tukey post-hoc), and inter-regional correlations were assessed with Pearson's r .

Results: Cortical/subchondral attenuation (SC 729.4 ± 213.9 HU; CO1 711.5 ± 271.1 HU; CO2 630.6 ± 282.7 HU) was substantially higher than trabecular attenuation (T1 294.0 ± 124.1 HU; T2 201.9 ± 93.3 HU). Men had significantly higher HU values than women in the trabecular and cortical rim regions (T1: 388.5 vs 254.9 HU; T2: 286.4 vs 166.9 HU; CO1: 818.4 vs 667.3 HU; CO2: 782.1 vs 568.0 HU; all $p \leq 0.008$); the subchondral region showed a similar but non-significant trend ($p = 0.066$). Trabecular HU declined significantly across age groups (ANOVA $p = 0.003$ for T1, $p = 0.019$ for T2), with the steepest fall after the sixth decade and most pronounced in women, whereas cortical attenuation declined more gradually and did not reach significance ($p = 0.053$ – 0.126). All five regions were positively inter-correlated ($r = 0.41$ – 0.78 , $p < 0.001$), with the strongest relationship between the two trabecular layers ($r = 0.78$).

Conclusion: Glenoid trabecular bone shows the steepest sex- and age-related decline in attenuation, while cortical bone is comparatively preserved. These locally derived normative HU values, obtainable opportunistically from routine thoracic CT without additional radiation, may assist radiologists and shoulder surgeons in preoperative bone-quality assessment, implant selection, and baseplate/screw trajectory planning for anatomic and reverse total shoulder arthroplasty.

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Introduction

The glenohumeral joint depends on an intact, well-mineralised glenoid to provide a stable platform for humeral head articulation and, in the reconstructed shoulder, for prosthetic component fixation. The scapula's glenoid fossa is a thin plate of cortical bone enclosing a comparatively sparse trabecular core, and its mechanical competence is determined largely by the density and distribution of this bone stock. Bone Mineral Density (BMD) is widely regarded as the principal determinant of bone strength, and diminished BMD is an established risk factor for fragility fracture and for failure of orthopaedic hardware placed within it.

In Total Shoulder Arthroplasty (TSA), and particularly in glenoid component fixation, inadequate bone mineral density is a recognised

contributor to early mechanical failure. Aseptic loosening of the glenoid component remains one of the most common modes of failure in anatomic TSA, and peg or screw fixation in Reverse Shoulder Arthroplasty (RSA) is similarly dependent on adequate purchase in host bone. Because glenoid BMD is not uniform cortical rim, subchondral plate, and trabecular core each behave differently a regional, rather than a single aggregate, assessment of bone quality is more informative for surgical planning than a global density figure.

Dual-energy X-ray absorptiometry (DXA), the reference standard for axial BMD measurement, is not practical for the glenoid because of its irregular shape and orientation. Quantitative CT-based attenuation measurement, expressed in Hounsfield units (HU), offers a practical surrogate: it can be performed retrospectively on any CT examination that includes the shoulder girdle, requires no dedicated acquisition, and correlates with true

volumetric BMD. Because a large proportion of thoracic CT examinations performed for unrelated indications already include the glenohumeral joint at their superior margin, HU values can, in principle, be extracted opportunistically providing bone-quality information without additional radiation exposure or cost, and well before a patient is ever referred for arthroplasty.

Several groups have reported regional glenoid BMD or HU values, predominantly using semi-automated volume-of-interest (VOI) segmentation in Western cohorts undergoing arthroplasty work-up, and typically in older or already symptomatic populations. Normative data derived from a non-pathologic population, using a simple, reproducible Region-Of-Interest (ROI) technique applicable to routine clinical CT, and specifically representative of a South Asian cohort, are lacking. The primary aim of this study was therefore to establish normative HU reference values for the adult glenoid across subchondral cortical, trabecular, and cortical rim regions in a non-pathologic Western Uttar Pradesh population, and to characterise their dependence on age and sex.

Materials and Methods

Study Design Setting and Population

This prospective, single-centre, cross-sectional study was conducted in the Department of Radiodiagnosis and Imaging at Teerthanker Mahaveer Hospital and Research Centre, College of Paramedical Sciences, Teerthanker Mahaveer University, Moradabad, Uttar Pradesh, India, over a one-year period. Consecutive adults aged 18–69 years who were referred to the department for high-resolution CT (HRCT) of the thorax for clinical indications unrelated to the shoulder were considered for inclusion. Patients with osteoporosis, any known bone-related or congenital skeletal disease, prior radiation therapy or chemotherapy, or radiographic evidence of glenohumeral joint pathology were excluded. A total of 106 patients met the inclusion criteria and were enrolled: 31 men and 75 women, with a mean age of 43.5 ± 14.6 years (range 18–68 years). For analysis, the cohort was stratified into five decade-based age groups: 18–29, 30–39, 40–49, 50–59, and 60–69 years.

Imaging Protocol

All examinations were performed on a 128-slice CT scanner (Philips Ingenuity Core) using a standard HRCT thorax protocol (120 kVp; section thickness 1.0–2.5 mm; high-spatial-resolution bone kernel), reconstructed with coronal reformats through

the glenohumeral joint. No additional acquisition, contrast administration, or radiation exposure beyond the clinically indicated thoracic examination was required to obtain glenoid HU measurements.

Region-of-Interest Measurement

On the coronal reformat that best demonstrated the glenoid cavity, the glenoid was divided into five contiguous regions, each interrogated with a standardised 2.5-mm square region of interest (area 80 mm²): a subchondral cortical region (SC) immediately beneath the articular surface, two successive trabecular layers extending medially from the subchondral plate (T1, adjacent to SC; T2, deeper), and two cortical rim regions corresponding to the anterior and posterior margins of the glenoid (CO1, CO2). Mean attenuation (in HU) was recorded for each region on every patient. All measurements were performed by a single reader using the scanner's integrated workstation software to minimise inter-observer variability.

Statistical Analysis

Continuous variables are presented as mean $\pm$ standard deviation (SD) and range; categorical variables as frequency and percentage. Regional HU values were compared between sexes using the independent-samples t-test, and across the five age groups using one-way analysis of variance (ANOVA), with Tukey's honestly significant difference test applied post hoc for the trabecular regions where the omnibus ANOVA was significant. Age-by-sex interaction was explored by comparing regional HU between sexes within each age group and by comparing HU across age groups separately within each sex. Pearson's correlation coefficient (r) was used to assess the relationship between the five regional HU measurements. A two-tailed p value < 0.05 was considered statistically significant. All analyses were performed using SPSS version 29.0.10 (IBM Corp., Chicago, IL).

Results

Cohort Characteristics

Of 106 patients analysed, 75 (70.8%) were women and 31 (29.2%) were men. Age distribution across the five decade-based groups is summarised in Table 1: 25 patients (23.6%) were aged 18–29 years, 15 (14.2%) 30–39 years, 22 (20.8%) 40–49 years, 27 (25.5%) 50–59 years, and 17 (16.0%) 60–69 years. The cohort's overall mean age was 43.5 ± 14.6 years (range 18–68 years).

Table 1: Demographic Characteristics of the Study Cohort (n = 106)

Characteristic	Category	n	%
Sex	Male	31	29.2
	Female	75	70.8
Age group (years)	18–29	25	23.6
	30–39	15	14.2
	40–49	22	20.8
	50–59	27	25.5
	60–69	17	16.0
Age, mean $\pm$ SD (range), years	43.5 $\pm$ 14.6 (18–68)		

Overall Regional HU Values

Across the whole cohort, subchondral and cortical rim regions showed markedly higher attenuation than trabecular regions: SC 729.4 ± 213.9 HU (range 248–1201), CO1 711.5 ± 271.1 HU (range 253–1379), and CO2 630.6 ± 282.7 HU (range 205–1753), compared with T1 294.0 ± 124.1 HU (range 103–700) and T2 201.9 ± 93.3 HU (range 59–450). The mean attenuation across the three cortical/subchondral regions (690.5 HU) was therefore approximately 2.8-fold higher than the mean of the two trabecular regions (247.9 HU).

Regional HU Values by Sex

Men had higher mean HU values than women in every region measured (Table 2). The difference reached statistical significance in both trabecular regions and both cortical rim regions (T1, T2, CO1, CO2; all $p \leq 0.008$), and was most pronounced in the trabecular layers, where men exceeded women by 133.6 HU in T1 (52% higher) and 119.5 HU in T2 (72% higher). The subchondral region showed a similar direction of difference (788.7 vs 704.8 HU) that did not reach significance ($p = 0.066$).

Table 2: Regional Glenoid HU Values by Sex

Region	Male, mean $\pm$ SD	Female, mean $\pm$ SD	t	p value	Significant
SC	788.7 $\pm$ 207.7	704.8 $\pm$ 213.0	1.86	0.066	No
T1	388.5 $\pm$ 140.8	254.9 $\pm$ 92.3	5.77	< 0.001	Yes
T2	286.4 $\pm$ 105.4	166.9 $\pm$ 60.2	7.36	< 0.001	Yes
CO1	818.4 $\pm$ 226.5	667.3 $\pm$ 277.0	2.69	0.008	Yes
CO2	782.1 $\pm$ 316.1	568.0 $\pm$ 243.6	3.76	< 0.001	Yes

Regional HU Values by Age Group

One-way ANOVA showed a significant effect of age group on both trabecular regions (T1: $F = 4.29$, $p = 0.003$; T2: $F = 3.09$, $p = 0.019$), with a consistent downward trend from the third to the seventh decade (Table 3). Cortical/subchondral regions showed the same directional decline but did not reach statistical significance (SC $p = 0.071$; CO1 $p = 0.053$; CO2 $p = 0.126$). Tukey post-hoc comparisons localised the trabecular difference to the oldest group: T1 was significantly lower in the 60–69-year group than in both the 18–29-year group (mean difference 121.6 HU, $p = 0.011$) and the 30–39-year group (mean difference 145.1 HU, $p = 0.006$), and T2 was significantly lower in the 60–69-year group than in the 18–29-year group (mean difference 91.5 HU, $p = 0.014$).

Table 3: Regional Glenoid HU Values by Age Group (One-Way ANOVA)

Region	18–29 y	30–39 y	40–49 y	50–59 y	60–69 y
SC	774.9 $\pm$ 244.8	831.9 $\pm$ 168.7	727.8 $\pm$ 203.2	651.7 $\pm$ 193.8	697.2 $\pm$ 214.2
T1*	338.7 $\pm$ 124.5	362.1 $\pm$ 132.3	278.4 $\pm$ 107.8	275.8 $\pm$ 121.1	217.1 $\pm$ 93.3
T2*	246.2 $\pm$ 98.4	214.7 $\pm$ 94.7	203.1 $\pm$ 84.5	182.3 $\pm$ 92.0	154.7 $\pm$ 73.6
CO1	750.1 $\pm$ 273.4	844.8 $\pm$ 295.7	750.6 $\pm$ 274.3	615.1 $\pm$ 248.8	639.8 $\pm$ 228.3
CO2	718.1 $\pm$ 296.3	711.1 $\pm$ 323.2	636.3 $\pm$ 250.9	547.4 $\pm$ 264.1	555.7 $\pm$ 264.2

Values are mean $\pm$ SD, in HU. *Significant one-way ANOVA across age groups (T1: $F = 4.29$, $p = 0.003$; T2: $F = 3.09$, $p = 0.019$); other regions not significant ($p > 0.05$).

Age-Sex Interaction

When age-group comparisons were repeated separately within each sex, the trabecular age effect was significant in men for both T1 ($F = 3.38$, $p = 0.023$) and T2 ($F = 3.81$, $p = 0.014$), whereas in women it was significant only for T1 ($F = 3.12$, $p = 0.020$) and did not reach significance for T2 ($F = 2.40$, $p = 0.058$). Directly comparing men and women within each age band (Table 4), the sex difference in trabecular HU was significant across most of the reproductive and middle-adult decades. T1 differed significantly between sexes in every group from 18–29 through 50–59 years, and T2 in the 18–29, 30–39, and 50–59-year groups but converged in the 60–69-year group, where male and female T2 values were nearly identical (154.8 vs 154.7 HU) and male T1 had fallen below the female value (202.0 vs 221.7 HU). This pattern indicates a proportionally steeper age-related decline in trabecular bone among men, such that the substantial sex gap present in early and middle adulthood narrows, and in the oldest decade effectively disappears, by the seventh decade.

Table 4: Regional Glenoid HU Values by Age Group, Stratified by Sex (Age-Sex Interaction)

Region	Age (y)	Male, mean $\pm$ SD	Female, mean $\pm$ SD	t	p
T1	18–29	434.2 $\pm$ 135.6	284.9 $\pm$ 80.3	3.48	0.002
	30–39	477.0 $\pm$ 166.9	320.4 $\pm$ 94.7	2.32	0.037
	40–49	355.3 $\pm$ 109.6	242.5 $\pm$ 89.1	2.57	0.018
	50–59	419.0 $\pm$ 106.4	225.7 $\pm$ 79.3	5.09	< 0.001
	60–69	202.0 $\pm$ 82.2	221.7 $\pm$ 99.1	−0.36	0.725
T2	18–29	341.2 $\pm$ 83.9	192.7 $\pm$ 57.2	5.27	< 0.001
	30–39	339.0 $\pm$ 65.3	169.6 $\pm$ 53.3	5.15	< 0.001
	40–49	242.9 $\pm$ 113.3	184.5 $\pm$ 63.7	1.56	0.135
	50–59	304.7 $\pm$ 77.9	139.5 $\pm$ 47.0	6.72	< 0.001
	60–69	154.8 $\pm$ 95.6	154.7 $\pm$ 70.3	0.00	0.999

Inter-Regional Correlations

All five regional HU measurements were positively and significantly correlated with one another (Table 5). The strongest relationship was between the two trabecular layers (T1–T2, $r = 0.78$, $p < 0.001$), followed by the two cortical rim regions (CO1–CO2, $r = 0.61$, $p < 0.001$). Correlations between trabecular and cortical/subchondral regions were more modest ($r = 0.41$ – 0.58 , $p < 0.001$), indicating that, while overall bone attenuation trends together across a given glenoid, cortical and trabecular compartments are not interchangeable and each carries distinct regional information.

Table 5: Consolidated Pearson Correlation Matrix of Regional Glenoid HU Values (n = 106)

	SC	T1	T2	CO1	CO2
SC	1	0.536	0.406	0.526	0.579
T1	—	1	0.777	0.519	0.556
T2	—	—	1	0.429	0.441
CO1	—	—	—	1	0.614
CO2	—	—	—	—	1

All coefficients $p < 0.001$.

Discussion

This study establishes normative, region-specific HU reference values for the adult glenoid in a non-pathologic South Asian cohort, using a simple ROI technique applicable to any CT that includes the shoulder girdle. Three findings are of particular relevance to preoperative planning: cortical/subchondral attenuation substantially exceeds trabecular attenuation at every age; men have significantly higher trabecular and cortical-rim HU than women through most of adulthood; and trabecular boneunlike cortical boneshows a statistically significant, non-linear decline with age that is most marked after the sixth decade and, notably, converges between sexes in the oldest patients.

Comparison with the Existing Literature

Reported normative glenoid BMD in 441 patients (310 men, 131 women, aged 18-69 years) using an automated volume-of-interest (VOI) technique on a six-segment glenoid model [1]. As in the present cohort, they found higher BMD in men than women across all age bands, and a comparable magnitude of trabecular decline with age (male trabecular BMD falling from approximately 400 HU in the third decade to 287 HU in the seventh; female trabecular BMD falling from approximately 329 to 239 HU over the same span). Our male trabecular values (434 HU at 18-29 years, declining to 202 HU at 60-69 years) and female values (285 HU declining to 222 HU) follow the same overall direction, though the present cohort shows a steeper apparent fall in men and a comparatively flatter trajectory in womena difference plausibly attributable to the smaller male sample here ($n = 31$) and to the conventional square-ROI technique used, versus Eghbali and colleagues’ semi-automated VOI segmentation.

Subsequently, quantified glenoid BMD using six VOIs in patients with glenohumeral osteoarthritis scheduled for anatomic TSA [2,3]. Comparing age-matched groups, their pathological-shoulder HU values in the cortical and deeper trabecular regions were broadly similar to the normative values reported here, though they recorded lower subchondral values and higher superficial trabecular values than the present study. Both prior series showed wider measurement variability than seen in our non-pathologic cohort consistent with the expectation that osteoarthritic and pre-arthroplasty glenoids, subject to altered loading and cavitation, deviate more heterogeneously from a normative baseline than the non-pathologic bone measured here. Mariaux and colleagues further demonstrated that lower preoperative glenoid BMD was associated with aseptic glenoid implant loosening, reinforcing the clinical rationale for the normative benchmarks established

in the present work: values that fall materially below the age- and sex-matched reference range described here may flag patients at elevated risk of fixation failure.

Using an earlier CT-based characterisation of glenoid bone across three shoulder pathologies, similarly reported a decline in HU with age, though their absolute values were lower than ours across most regions likely reflecting both the pathological nature of their cohort and differences in scanner generation and reconstruction technique [4]. Encouragingly, in patients over 60 years, their reported mean HU was close to the value found in the corresponding decade of the present, non-pathologic cohort, suggesting that by the seventh decade, age-related bone loss may narrow the gap between pathological and non-pathological glenoid bone qualityconsistent with the sex-convergence pattern observed in our own oldest age group.

Clinical Relevance

Regional, rather than global, HU assessment is directly relevant to both anatomic and reverse shoulder arthroplasty. In anatomic TSA, glenoid component fixation depends heavily on subchondral and cortical rim bone quality, since the implant keel or pegs typically engage this region after reaming; the present data suggest that women and older patientsparticularly those beyond the sixth decademay present with reduced trabecular support beneath an apparently intact cortical rim, a distinction that could inform reaming depth and cementing technique. In reverse shoulder arthroplasty, baseplate and peripheral screw fixation depend on engaging denser regions of the scapula; knowing that trabecular attenuation falls disproportionately relative to cortical bone with age and in women supports a preoperative CT-based check of regional bone quality obtainable, per this study’s central premise, opportunistically from any prior thoracic CT to guide screw trajectory toward better-preserved cortical bone stock and to flag patients for whom additional fixation augmentation or a cementless-to-cemented technique switch may reduce the risk of aseptic loosening.

Limitations

This study has several limitations. First, the male subgroup was relatively small ($n = 31$) relative to the female subgroup ($n = 75$), which may have reduced precision of the male-specific age-stratified estimates and could partly explain the steeper apparent male trabecular decline relative to prior series. Second, HU values were measured using a fixed 2.5-mm two-dimensional square ROI rather than a three-dimensional volume-of-interest (VOI)

model; while this conventional technique is simple, reproducible, and requires no specialised segmentation software supporting its opportunistic use on routine clinical CT it samples a smaller and potentially less representative volume of bone than VOI-based methods, which may explain some of the wider measurement range observed here relative to VOI-based literature. Third, this was a single-centre study conducted at one institution in western Uttar Pradesh using a single CT scanner model, which may limit generalisability to other populations, scanner platforms, and reconstruction protocols; multicentre validation with cross-calibration against phantom-based BMD measurement would strengthen these reference values before wider clinical adoption.

Conclusion

In a non-pathologic adult population, glenoid cortical and subchondral bone attenuation substantially exceeds trabecular attenuation, and both display significant sex differences and an age-related decline that is most pronounced, and most clinically important, in trabecular bone after the sixth decade. These normative, age- and sex-specific HU reference values derived using a simple ROI technique applicable to routine, non-dedicated thoracic CT provide radiologists and shoulder surgeons with a practical, cost-neutral benchmark for opportunistic preoperative bone-quality assessment, supporting individualised implant selection, reaming strategy, and screw trajectory planning in anatomic and reverse total shoulder arthroplasty [5-17].

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