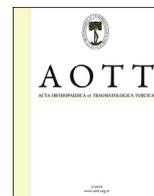


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The relationship between age, rotator cuff integrity, and osseous microarchitecture of greater tuberosity: Where should we put anchor?

Erica Kholinne ^{a, d}, Hyun Joo Lee ^b, Sung Jung Kim ^c, So Hyun Park ^d, In-Ho Jeon ^{d, *}^a Department of Orthopedic Surgery, St. Carolus Hospital, Jakarta, Indonesia^b Department of Orthopedic Surgery, Kyungpook National University Hospital, Daegu, South Korea^c Department of Plastic Surgery, W Hospital, Daegu, South Korea^d Department of Orthopedic Surgery, Asan Medical Center, University of Ulsan College of Medicine, Seoul, South Korea

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ABSTRACT

Objective: The aim of this study was to compare the microarchitecture of the greater tuberosity with or without rotator cuff tear and to obtain optimum location for anchor screw insertion for rotator cuff repair. **Methods:** Twenty-five humeral heads were harvested from 13 male cadavers of mean age 58.4 years, including 6 humeri with rotator cuff tear and 19 intact humeri. Six regions of interest (proximal, intermediate, and distal zones of the superficial and deep regions) were divided into the anterior (G1), middle (G2), and posterior (G3) areas of the greater tuberosity. Trabecular bone volume and cortical thickness were evaluated. **Results:** Total trabecular bone volume was greater in subjects <50 years old than in subjects >50 years old but did not differ significantly in subjects with and without rotator cuff tear. Cortical thickness in both intact and torn rotator cuff groups was significantly greater in the proximal and intermediate zones than in the distal zone. Cortical thickness was related to anatomic location rather than age or cuff tear. **Conclusion:** The optimal location for anchor screw insertion during rotator cuff repair is either the proximal or intermediate region of the greater tuberosity. Age has more influence in terms of trabecular bone volume loss than rotator cuff integrity.

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Introduction

Surgical repair for rotator cuff tear include arthroscopic repair with suture anchor screws. Many factors will determine the successful of rotator cuff repair. One of which is bone quality of the

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* Corresponding author. Department of Orthopedic Surgery, Asan Medical Center, School of Medicine, University of Ulsan, 86 Asanbyeongwon-gil, Songpa-gu, Seoul, 138-736, South Korea. Fax: +82 2 488 7877.

E-mail address: jeonchoi@gmail.com (I.-H. Jeon).

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tuberosity.¹ Poor bone quality may cause failure of such as loosening of anchor screws that will leads to failed repair.

Studies of the bony architecture of the proximal humerus have reported that bone density decreases with age and varies between each individuals.² Bone density of the humeral head has been reported to correlate with the pull-out strength of suture anchor screws.^{3,4} Therefore, the need for radiographic study of the microarchitecture of the greater tuberosity is required. High resolution computed tomography (HRCT) has been reported to accurately evaluate bony microarchitecture,⁵ still it has not been applied to evaluate detail microarchitecture around the greater tuberosity.

This study was designed to investigate the regional variation in bone quality parameters in the greater tuberosity correlated with rotator cuff integrity, and to provide optimal location for anchor screw insertion for rotator cuff surgery. HRCT was used to compare bone quality parameters, including trabecular bone volume and cortical thickness, in subjects with and without rotator cuff tear.

Materials and methods

Sample preparations

Twenty-five humeral heads were harvested from 13 fresh male cadavers. Exclusion was made to humeri with bone lesions, fractures, tumors and of which had undergone surgical treatment.

Radiological examination

Three-dimensional quantitative CT scan

All humeri were scanned with 16 slice, 0.625 mm thickness, 64-row multi-detector CT helical scanner (LightSpeed VCT, GE Healthcare, Milwaukee, Wisconsin). Images underwent volume rendering, using a 512×512 matrix and a 140×140 mm field of view. Image data were obtained with Advantage Workstation 4.3 and saved as DICOM files and later processed and analyzed with Centricity AW Suite (GE Healthcare).

Regions of interest (ROIs)

The greater tuberosity was divided into anterior (G1), middle (G2) and posterior (G3) areas in respect to the biceps groove in the axial plane (Fig. 1-A). Coronal plane division of articular surface was made as proximal (supraspinatus attachment), intermediate

(greater tuberosity protrusion) and distal areas (10 mm below intermediate areas) (Fig. 1-B). Each zone was subdivided according to its depth. Superficial zone was the area just below the outer cortex while deep zone was 10 mm below it. This division was made based on anchor's length used in rotator cuff repair (Fig. 1-C). A final ROIs were defined. A cubic ROI was placed in each region with ≥ 0.3 mm in vertical axis and ≥ 5 mm in length. Trabecular bone volume was defined as the ratio of bone volume to total volume and measured. Cortical thickness were measured in each cubic ROI and analyzed.

Statistical analysis

Differences in trabecular bone volume and cortical thickness of G1, G2, and G3 were analyzed with one-way ANOVA.

Trabecular bone volume and cortical thickness of specific ROIs were compared using independent t-tests, and the differences in greater tuberosity microarchitecture with and without rotator cuff tear were compared for each ROI.

Regression analysis test were used to evaluate the relationship between total trabecular bone volume for each ROIs and age.

Specimens were also divided into those <50 and >50 years old, and differences for each ROI in samples with and without rotator cuff tear were analyzed by ANCOVA.

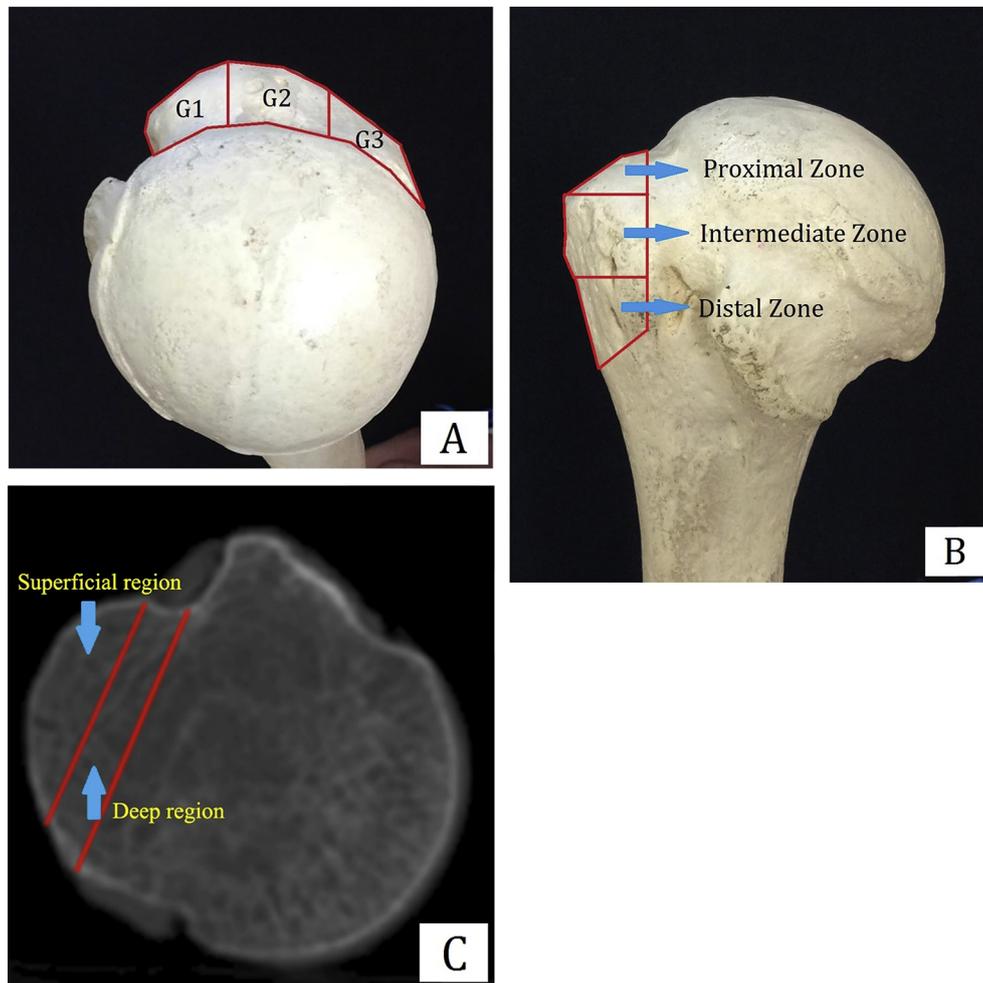


Fig. 1. Regions of Interest, (A) On an axial view of the humeral head, where the bicipital groove appears, the greater tuberosity was divided into three areas: (G1), middle (G2), and posterior (G3). (B) On a coronal view of the humeral head, the margin between the articular surface and greater tuberosity was defined as proximal, the apex of the greater tuberosity as intermediate, and 1 cm distal to the apex of the greater tuberosity as distal zone. (C) Each zone were divided according to its depth into superficial and deep regions.

Table 1
The relationships among age, rotator cuff tear and bone loss.

Region	Age		Rotator cuff tear		Age*Rotator cuff tear				
	β	p-value	β	p-value	r2	f-value	p-value		
Trabecular bone	Superficial	G1	-0.73	0.01*	3.43	0.75	0.26	3.81	0.04*
		G2	-0.84	0.00*	8.09	0.29	0.48	10.17	0.00*
		G3	-0.80	0.01*	-0.37	0.97	0.32	5.11	0.02*
	Deep	G1	-0.11	0.03	2.35	0.24	0.21	2.89	0.08
		G2	-0.48	0.04	5.75	0.52	0.18	2.43	0.11
		G3	-0.47	0.01*	-3.57	0.57	0.33	5.45	0.01*
		Total	-0.59	0.00	-3.38	0.45	0.59	16.07	0.00*
Cortical bone	G1	-0.01	0.31	-0.28	0.22	0.04	1.62	0.21	
	G2	0.00	0.76	-0.19	0.44	0.01	0.42	0.66	
	G3	0.00	0.78	0.01	0.98	0.00	0.04	0.96	
	Total	0.00	0.55	-0.14	0.28	0.01	0.93	0.40	

*Statistically significant with p < 0.05.

All statistical analyses were performed using SPSS for Windows version 12.0. A p value < 0.05 was considered statistically significant.

Results

Basic demographic result

The mean age of cadaver were 58.4 years. The mean ages of subjects with and without rotator cuff tears were 64.6 years and 56.4 years, respectively. All rotator cuff tears had medium sized tear at the supraspinatus, four in the right shoulder and two in the left shoulder. Six of 25 humeral heads had rotator cuff tear. Of the 19 humeri with intact rotator cuffs, nine were right and ten were left shoulders. Subject with rotator cuff tear were older than those with intact rotator cuffs (64.6 years vs. 56.4 years).

Trabecular bone volume

Trabecular bone volume at superficial region for G1–G3 showed significant variability towards age and rotator cuff integrity (r2 = 0.26, 0.48, 0.32 respectively for p < 0.05). However, the same significant variability only shown at G3 deep region (r2 = 0.33) (Table 1).

Total trabecular bone volume, was significantly lower in subjects aged <50 years than in those aged >50 years (31.86 ± 11.31% vs. 49.99 ± 10.10%, p < 0.05) (Table 2).

Comparisons of total trabecular bone volume in each zone of G1, G2, and G3 showed no significant differences in samples with and without rotator cuff tears, except for G1 with intact cuffs. In the superficial and deep regions of G1 in the rotator intact group, trabecular bone volume was significantly higher in the intermediate zone than in the distal and proximal zones (Table 3) (Fig. 2). The total trabecular volume for adjusted age in both group in each zone did not show significant different in subjects with or without rotator cuff tears (Table 4).

Cortical bone thickness

Cortical thickness was not found to be correlated significantly with age and rotator cuff tear when analyzed by regression analysis method (Table 1). Cortical thickness was significantly higher at intermediate and distal zone in intact rotator cuff group. In both

Table 2
Total trabecular bone volume for each age group.

<50 yrs (n = 9)		>50 yrs (n = 16)		p
Mean	S. D	Mean	S. D	
49.99	10.10	31.86	11.31	0.001

Table 3
Trabecular bone volume relative to ROIs in each region.

Region Of Interest	Rotate Cuff Tear (-) (n = 19)		Rotate Cuff Tear (+) (n = 6)		t-value (p-value) ^a	
	Mean	S. D	Mean	S. D		
G1 Superficial	Prox	25.70	25.90	23.13	21.02	0.22 (0.83)
	Inter	39.45	26.1	24.68	35.66	1.10 (0.28)
	Dist	15.50	15.66	13.20	26.56	0.26 (0.79)
	F-value (p-value) ^b	5.15 (0.01*)		0.29 (0.75)		
	Post hoc (Duncan)	(Dist,pro)<Inter				
G1 Deep	Prox	4.57	4.35	6.00	4.64	-0.69 (0.50)
	Inter	13.34	18.06	15.12	24.68	-0.19 (0.85)
	Dist	17.06	15.67	9.62	11.93	1.06 (0.30)
	F-value (p-value) ^b	3.97 (0.03*)		0.49 (0.62)		
	Post hoc (Duncan)	pro<(Inter,Dist)				
G2 Superficial	Prox	23.88	19.41	25.08	25.60	-0.12 (0.90)
	Inter	32.81	28.67	27.80	36.74	0.35 (0.73)
	Dist	24.12	19.84	12.60	21.23	1.22 (0.24)
	F-value (p-value) ^b	0.93 (0.40)		0.48 (0.63)		
	Post hoc (Duncan)					
G2 Deep	Prox	11.85	16.83	11.43	19.16	0.05 (0.96)
	Inter	8.10	11.84	12.10	27.70	-0.51 (0.61)
	Dist	7.45	8.63	11.15	21.96	-0.40 (0.70)
	F-value (p-value) ^b	0.65 (0.53)		0.00 (1.00)		
	Post hoc (Duncan)					
G3 Superficial	Prox	34.63	24.72	27.67	26.23	0.59 (0.56)
	Inter	29.25	26.42	24.23	36.67	0.37 (0.72)
	Dist	25.85	23.04	20.95	26.39	0.44 (0.67)
	F-value (p-value) ^b	0.61 (0.55)		0.07 (0.93)		
	Post hoc (Duncan)					
G3 Deep	Prox	19.29	16.37	7.73	6.52	2.47 (0.02)
	Inter	16.71	13.96	14.77	27.80	0.23 (0.82)
	Dist	14.96	19.27	8.50	16.98	0.73 (0.47)
	F-value (p-value) ^b	0.31 (0.74)		0.24 (0.79)		
	Post hoc (Duncan)					
Total	40.37	13.01	32.10	15.96	1.29 (0.21)	

*Statistically significant with p < 0.05.

^a Independent T-test for the comparison between RCT(-) and RCT(+).

^b One-way ANOVA for the comparison of Proximal, Intermediate, Distal region.

intact and torn rotator cuff group, cortical thickness was always lower in distal zone. In intact rotator cuff group, G1 and G2 showed the highest cortical thickness at intermediate zone, while G3 showed the highest cortical thickness at proximal zone. In torn rotator cuff group, G1 and G3 showed the highest cortical thickness at proximal zone, while G2 showed the highest cortical thickness at intermediate zone (Table 5) (Fig. 3).

Discussion

Rotator cuff tear is a common shoulder pathology in elderly age group. Rotator cuff repair may fail for various causes. Although the role of repair techniques has been studied widely, still there is little

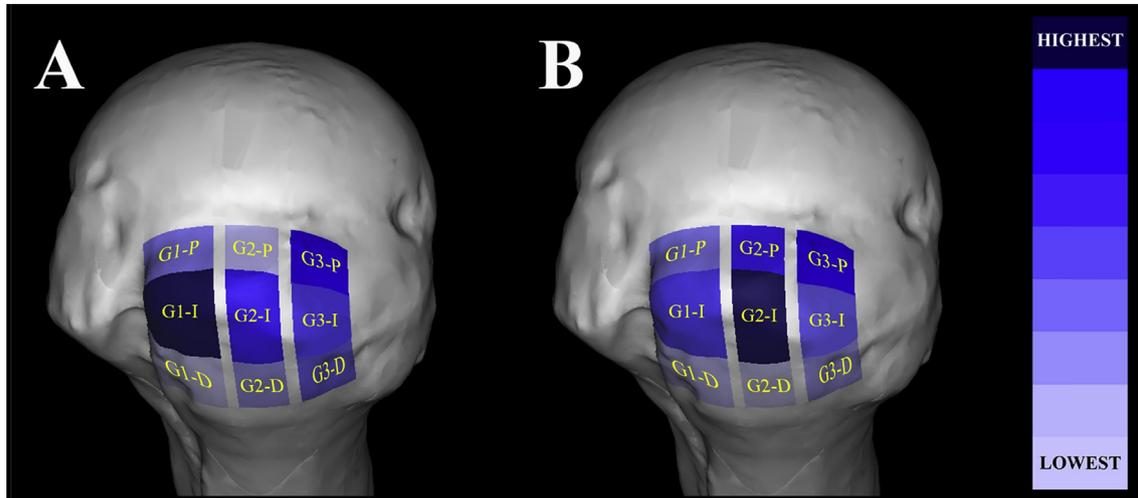


Fig. 2. Overall schematic drawing showing each zone in G1, G2, and G3. Trabecular bone volume in the superficial region with intact (a) and torn (b) rotator cuffs. Dark blue indicates higher bone volume, and light blue indicates lower bone volume. G1-P: proximal zone of G1, G1-I: intermediate zone of G1, G1-D: distal zone of G1, G2-P: proximal zone of G2, G2-I: intermediate zone of G2, G2-D: distal zone of G2, G3-P: proximal zone of G3, G3-I: intermediate zone of G3, G3-D: distal zone of G3.

Table 4
Total trabecular bone volume comparison between intact and torn rotator cuff group.

		Intact Rotator Cuff (n = 19)		Torn Rotator Cuff (n = 6)		F-value (p-value)
		LSmean	S. E	LSmean	S. E	
Superficial	prox	22.227	3.556	30.316	6.401	1.201 (0.285)
	Inter	30.518	5.452	35.042	9.813	0.160 (0.693)
	Dist	22.669	3.691	17.18	6.644	0.513 (0.481)
Deep	prox	10.908	3.6	14.424	6.479	0.221 (0.643)
	Inter	7.145	3.389	15.123	6.1	1.287 (0.269)
	Dist	6.62	2.471	13.786	4.448	1.952 (0.176)
total		16.66	3.058	21.042	5.505	0.447 (0.497)

Table 5
Cortical thickness relative to ROIs in each region.

Region Of Interest		Intact Rotator Cuff (n = 19)		Torn Rotator Cuff (n = 6)		t-value (p-value) ^a
		Mean	S. D	Mean	S. D	
G1	Prox	2.18	0.72	2.43	0.73	-0.74 (0.47)
	Inter	2.20	0.75	1.28	0.47	2.77 (0.01*)
	Dist	1.14	0.27	0.80	0.28	2.71 (0.01*)
F-value (p-value) ^b		17.99 (0.00*)		15.22 (0.00*)		
Post hoc (Duncan)		Dist < (Prox, Inter)		(Dist, Inter) < Prox		
G2	Prox	2.05	0.50	2.10	0.61	-0.22 (0.83)
	Inter	2.71	0.70	2.22	0.87	1.42 (0.17)
	Dist	1.05	0.33	0.88	0.32	1.08 (0.29)
F-value (p-value) ^b		47.22 (0.00*)		8.02 (0.00*)		
Post hoc (Duncan)		Dist < Prox < Inter		Dist < (Prox, Inter)		
G3	Prox	2.28	1.36	2.57	1.39	-0.44 (0.66)
	Inter	2.05	0.67	2.00	1.26	0.12 (0.90)
	Dist	1.76	0.62	1.30	0.25	1.74 (0.10)
F-value (p-value) ^b		1.48 (0.24)		2.02 (0.17)		
Post hoc (Duncan)						

^a Statistically significant with p < 0.05.

^a Independent T-test for the comparison between RCT(-) and RCT(+).

^b One-way ANOVA for the comparison of Proximal, Intermediate, Distal region.

information on the quality of the bone to which tendon is inserted. The regional differences of bone quality of elderly group age have to be carefully considered to assure stable anchor fixation in rotator cuff repair. Loosened anchor screw will lead to repair failure. Thus,

reduced bone density in the greater tuberosity is associated with repair failure and re-tearing of the rotator cuff.^{1,4,6}

Previous author have studied the microstructure of humeral head has its variability for its three-dimensional bone density.⁷ Nevertheless, there is little information regarding bony micro-architecture of the greater tuberosity, to which the anchor screws must be inserted. High-resolution micro-CT assessment of cadaveric humeri specimens showed that rotator cuff tears reduced cancellous bone density in the greater tuberosity over 50%, but had no effect on cortical thickness.⁶ These findings suggested that anchor screws can be positioned subcortically or medially under the articular surface.

Our study compared intact and torn rotator cuffs group in which 9 ROIs which comprise whole greater tuberosity were analyzed. To our knowledge, this is the first study to cover all GT foot print with both intact and torn rotator cuff tear. For torn rotator cuff group, in anterior and middle part (axial cut), trabecular bone volume was found to be highest in the greater tuberosity protuberance (intermediate zone). Exception has been found for posterior part, that trabecular bone volume was found to be highest at the supraspinatus attachment (proximal zone). This result was supported by previous study by Tingart et al.^{7,8} Tingart et al (2006) studied the regional differences in bone mineral density of the humeral head. They defined five regions of interest in the humeral head (superior-anterior, superior-posterior, central, inferior-anterior, and inferior-posterior) showed that trabecular bone volume was lower in the superior-anterior region of interest and was higher in the central portion. Their study showed that placement of cancellous screw in regions with higher trabecular bone volume may prevent implant loosening.⁷ Tingart et al (2014) found that trabecular and cortical bone mineral densities was significantly higher in the proximal than distal part of the greater tuberosity, suggesting that anchor screws be inserted into the proximal part.⁸ They found that poor bone quality resulted in anchor loosening and tendon re-rupture. However, all rotator cuff tendon was intact in this study. However, Rossouw et al opposed this and found that pull-out strength of anchor screws located 25 mm distal to the greater tuberosity tip was higher than those placed at the medially and at the edge of the articular cartilage.⁹ In their study all specimens were with intact rotator cuff.

Cortical thickness is important for determining the pull-out strength of anchor screws.¹⁰ The study presented here showed

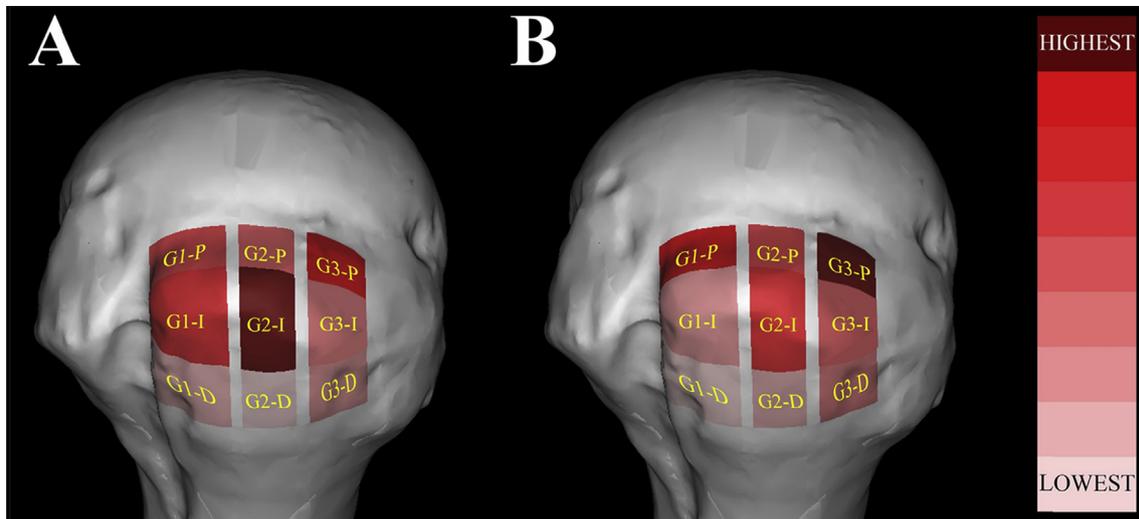


Fig. 3. Cortical bone thickness with intact (a) and torn (b) rotator cuffs. Dark red indicates greater cortical thickness, and light red indicates lower cortical thickness. G1-P: proximal zone of G1, G1-I: intermediate zone of G1, G1-D: distal zone of G1, G2-P: proximal zone of G2, G2-I: intermediate zone of G2, G2-D: distal zone of G2, G3-P: proximal zone of G3, G3-I: intermediate zone of G3, G3-D: distal zone of G3.

that cortical thickness was significantly greater in the supraspinatus attachment (proximal zone) and greater tuberosity protuberance (intermediate zones) of anterior and middle part in axial cut in subjects with both intact and torn rotator cuffs. These findings suggest that, to enhance biomechanical stability, anchor screws should be inserted in between supraspinatus attachment to the greater tuberosity protuberance region. Study by Amis also supported with their finding for pull-out strength of ligament anchors was proportionally related to the cortical thickness.¹¹ Hecker et al reported anchor placement to the metaphyseal bone was stronger than cancellous bone.¹² This are obviously divine since cortical bone is thirty times stronger than cancellous bone.^{13,14}

This study had several limitations, including the use of cadaveric humeri (ex vivo samples). Results may differ in vivo. Also, the duration of rotator cuff tear and any associated muscle atrophy and bone loss were not considered due to the inherent limitations of a cadaveric study. Clinical studies with large numbers of patients are required to confirm and extend these findings.

Conclusions

The optimal location for insertion of the anchor screw is the proximal or intermediate zone of the greater tuberosity. In contrast to age, rotator cuff tear was not associated with loss of trabecular bone volume in the greater tuberosity. Cortical thickness was more related to anatomic location rather than age or cuff tear.

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