Differences in Coracoid and Glenoid Dimensions Based on Sex, Race, and Age: Implications for Use of the Latarjet Technique in Glenoid Reconstruction

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Abstract *Background:* The Latarjet procedure restores shoulder stability through reconstruction of the glenoid arc. Prior investigations of glenoid and coracoid dimensions have been underpowered to detect differences based on sex and race. *Questions/Purposes:* We sought to establish normative values for glenoid width and coracoid dimensions based on sex, race, and age. In addition, we assessed the restoration of glenoid dimensions using the classic and modified Latarjet techniques (classic technique: placing lateral surface of the coracoid to the glenoid; modified technique: placing inferior surface of the coracoid to the glenoid). *Methods:* A total of 993 cadaveric specimens ($n = 1986$ scapulae) from people over 18 years of age at the time of death were analyzed. Measurements of maximal glenoid width, coracoid width, thickness, and length were recorded. Statistical analysis was performed to detect differences based on sex and race, while univariable linear regression was used to determine the association of increasing age on measured dimensions. *Results:* All dimensions of specimens were significantly larger in males than in females. Caucasians possessed larger mean glenoid width, coracoid width, and coracoid length, while coracoid thickness was

significantly larger in African Americans. Linear regression analysis found that increasing age was associated with increased glenoid width and coracoid dimensions. Coracoid positioning restored glenoid width in defects measuring 20% of glenoid width using both classic and modified Latarjet techniques, while defects measuring up to 25% were more accurately reproduced using the modified technique. *Conclusion:* Dimensions were significantly larger in males and in Caucasians, aside from coracoid thickness. Mean dimensions increased with advancing age. Coracoid positioning using classic or modified Latarjet techniques restored glenoid width defects measuring 20% of the glenoid width, while the modified technique allowed for restoration of larger defects.

Keywords coracoid · Latarjet · glenoid · cadaver

Introduction

As the most inherently unstable joint in the body, the glenohumeral joint is prone to frequent dislocations, resulting in acute fracture or gradual bone loss from the anterior glenoid and leading to recurrent instability, additional injury, and pain [31, 33, 35]. In the setting of significant glenoid bone loss, generally defined as deficits measuring more than 20% of glenoid width [5, 9, 11, 20, 25, 27], bony augmentation procedures are required to restore glenohumeral stability, minimizing the risk of recurrent instability and attritional bone loss [10, 18]. While numerous investigations have examined reconstructing the bony glenoid utilizing autologous bone transferred from the iliac crest, distal tibia, or femoral head or from allograft bone [19, 28, 29], bony transfer from the coracoid is more common [1, 10, 38].

The Latarjet procedure, involving transfer of bone from the coracoid to the anterior glenoid, serves to restore the surface area and articular arc of the glenoid, reducing contact pressures and providing glenohumeral stability [7, 14, 17, 27]. Meanwhile, concomitant transfer of the coracoclavicular ligament

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and conjoint tendon provides further stability through the “sling effect,” while also vascularizing the graft [17]. Pre-operative planning is essential to ensuring an appropriate amount of coracoid is available to reconstruct the anteroinferior glenoid. Studies examining pre-operative assessment of the coracoid process have utilized both radiologic [4] and three-dimensional computed tomography (CT) [12, 21] to predict the amount of bone necessary for glenoid reconstitution while preventing complications associated with inadequate reconstruction [2, 6].

The classic Latarjet procedure involves osteotomy at the elbow of the coracoid, followed by transfer to the anterior glenoid, fixed so that the lateral surface is secured flush with the articular surface of the glenoid [22]. In contrast, the modified Latarjet consists of rotating the coracoid 90° along its longitudinal axis so that the curvature on the inferior surface of the coracoid better recreates the glenoid arc, thereby improving congruity and stability [3, 14]. Previous investigations have shown the modified Latarjet enables reconstitution of significantly greater bone deficiency due to the coracoid being wider than it is thick, along with better normalization of articular contact pressures [3, 17]. However, no current consensus exists on the optimal orientation of the coracoid graft in properly reconstructing glenoid width to minimize recurrent instability [6].

While prior investigations have examined the amount of coracoid bone available for transfer [15], authors have noted subtle differences in the bony dimensions of the glenoid and coracoid based on sex and race [13, 24, 26, 30, 32, 37]. However, these studies have been largely underpowered to determine significant differences in coracoid anatomy based on sex and race, while no study has examined changes based on patient age. The purpose of this investigation was to establish normative values for glenoid width and coracoid dimensions (length, width, and thickness) using a cadaveric collection to better understand differences in the relevant bony dimensions critical to successful Latarjet surgery based on sex, race, and age. The authors hypothesized that there would be no significant difference in glenoid width and associated coracoid dimensions based on sex, race, or age and no significant difference between classic and modified Latarjet techniques in the ability to recreate the glenoid in the setting of 20 or 25% of glenoid width bone loss.

Materials and Methods

This study did not involve live human subjects and was therefore exempt by the authors’ institutional review board. A total of 993 specimens (1986 scapulae) with matching right and left scapulae were analyzed from the Hamann-Todd Osteological Collection at the Cleveland Museum of Natural History. Inclusion criteria included scapulae with intact coracoid and glenoid anatomy from human skeletons over the age of 18 years at the time of death with corresponding demographic information including age at death and ethnicity. Specimens were excluded if either the right or the left scapula featured any bone loss or osteophytes precluding reliable measurements of the coracoid ($n = 16$

scapulae) or glenoid ($n = 7$ scapulae). All available specimens meeting inclusion criteria were included within the analysis.

Glenoid width was measured at the maximal anterior-to-posterior width of the glenoid rim (Fig. 1). Coracoid thickness and width were measured 10 mm from the tip of the coracoid. Coracoid thickness was measured from anterior to posterior (Fig. 2a) and width from medial to lateral (Fig. 2b). Coracoid length was measured from the distal tip of the coracoid to the knee (Fig. 3). All measurements were made using a digital caliper with accuracy to 0.01 mm (Mitutoyo Corp., Japan). To establish inter-observer reliability, 20 specimens ($n = 80$ measurements) were randomly chosen, positioned, and measured independently by two authors. Intra-class correlation coefficients (ICCs) were calculated between measurements. The authors considered an ICC of less than 0.4 to be poor, 0.4 to 0.75 to be fair to good, and more than 0.75 to be excellent, based on established recommendations [16, 34]. Remaining specimens were measured by a single author blinded to specimen race, sex, and age to minimize bias.

Measurements of the right and left scapulae were averaged so that a single value was reported for all specimens. All data were assessed for normality, and we found that the data for each outcome variable were normally distributed. Differences in race and sex were assessed for each outcome variable using an independent t test that did not assume equal variance across groups. Differences in age were analyzed using repeated measures of analysis of variance (ANOVA). The association between a 1-year increase in age on each of our outcome variables was assessed using a unique univariable linear regression model for each outcome, with age as the only independent variable in each model. A $p < 0.05$ was considered to be statistically significant.

We next assessed the ability to reproduce the width of the glenoid in the setting of glenoid bony loss based on the position of graft fixation to the glenoid,

Fig. 1. Measurement of the width of the glenoid rim using digital calipers at the point of greatest anterior-to-posterior width.

Fig. 2. Measurements of **a** coracoid thickness from anterior to posterior and **b** coracoid width from medial to lateral, as measured 10 mm from coracoid tip.

comparing classic versus modified Latarjet techniques. Using a hypothetical model, we calculated the glenoid width in the setting of 20 and 25% bony loss. We next calculated the ratio of bone available by dividing the amount of bone capable of restoring glenoid width based on graft placement (classic Latarjet technique: placing lateral surface of the coracoid to the glenoid vs. modified Latarjet technique: placing inferior surface of the coracoid to the glenoid) by the amount of bone lost in 20 and 25% loss settings. The mean overall ratios based on the technique were calculated, while subgroup analysis between techniques was evaluated based on sex, ethnicity, and age.

Fig. 3. Measurement of coracoid length, from distal tip to coracoid knee.

Results

Inter-observer ICC for glenoid and coracoid measurements was excellent, with a calculated value of 0.92. When Caucasian and African American specimens were compared, Caucasians were significantly older at the time of death than African Americans ($p < 0.001$). Measurements of mean glenoid width and coracoid width and length were significantly greater in Caucasian specimens than in African American specimens. African American specimens possessed significantly greater coracoid thickness ($p = 0.02$) (Table 1).

In documenting sexual differences, males were significantly older at the time of death than were females ($p < 0.001$). Furthermore, male specimens possessed significantly larger dimensions with each measured variable than did female specimens ($p < 0.001$) (Table 2).

Analysis based on age found that glenoid and coracoid dimensions were greater with increasing age at the time of death (Table 3). Linear regression analysis showed, for every 1-year increase in age, an associated 0.056-mm increase in glenoid width, 0.043-mm increase in coracoid width, 0.011-mm increase in coracoid height, and 0.044-mm increase in coracoid length (all $p < 0.001$).

Restoration of glenoid width based on Latarjet technique found that the modified Latarjet technique provided significantly more available bone than the classic Latarjet technique in models of 20% glenoid bone loss (ratio, 2.73 vs. 1.63, respectively; $p < 0.001$) and 25% glenoid bone loss (2.18 vs. 1.30, respectively; $p < 0.001$). Furthermore, no specimens in which glenoid width restoration was calculated using the modified technique had less bone than would be required to restore glenoid bone defects of 20 or 25%. Using the classic technique, no specimens had inadequate available bone to reconstruct defects measuring 20%, while 31 specimens ($n = 34$ scapulae; $n = 19$ Caucasian males, $n = 3$ Caucasian females, $n = 5$ African American males, $n = 4$ African American females) had inadequate bone to reconstruct defects measuring 25% of the glenoid width. The subgroup analysis found that the classic technique provided significantly more bone in specimens from

Table 1 Measurements of glenoid and coracoid dimensions based on race

	Caucasian	African American	<i>p</i> value
Total number subjects (specimens)	541 (1082)	452 (904)	–
Mean age (years)	55.4 ± 14.1	42.4 ± 14.3	< 0.001
Mean glenoid width (mm)	29.2 ± 2.5	28.1 ± 3.0	< 0.001
Mean coracoid width (mm)	15.9 ± 1.9	15.3 ± 2.1	< 0.001
Mean coracoid thickness (mm)	9.2 ± 1.2	9.4 ± 1.4	0.02
Mean coracoid length (mm)	46.0 ± 3.7	44.4 ± 4.2	< 0.001

African Americans than in those from Caucasians in both 20 and 25% bone-loss settings (Table 4). Meanwhile, the modified technique provided significantly more bone in specimens from males than in specimens from females in both 20 and 25% bone-loss settings. Significantly less bone was available with increasing age using the classic technique. In contrast, the modified technique provided significantly more bone with increasing age.

Discussion

In this osteologic investigation, we evaluated the differences in glenoid width and coracoid length, width, and height in cadaveric specimens based on race, sex, and age at the time of death. The primary findings based on our hypothesis were Caucasians had significantly greater dimensions except for coracoid thickness, which was significantly greater in African Americans; all measured dimensions were significantly greater in specimens taken from males than in those taken from females; all measured dimensions increased with advancing age at the time of death; and both coracoid positioning techniques reproduced glenoid width at 20% bone loss, while the modified Latarjet technique provided sufficient bone to reproduce glenoid width with increasingly larger glenoid bone defects.

This study is not without limitations. The authors were limited to the specimens available for examination within the collection; only available specimens meeting strict inclusion/exclusion criteria were used. This resulted in Caucasian and male specimens possessing significantly older ages at the time of death when compared to African Americans and females. The authors used only specimens from African Americans and Caucasians; specimens from different ethnic backgrounds such as Asian American were too few to perform meaningful statistical analysis. No historical information exists for any individuals within the collection regarding history of shoulder surgery or instability; however,

specimens with anomalous anatomy suggestive of prior operations or injury were excluded. The soft tissue and muscles surrounding the shoulder have been shown to provide additional stability following glenoid augmentation, but only the bony anatomy was measured in this investigation because the influence of the “sling effect” is unknown.

Reconstructing the radius of the glenoid curvature has been shown to be essential in ensuring optimal stability of the repair [14, 27]. In this study, only the width of the glenoid was measured, preventing analysis of the amount or dimensions of the coracoid necessary to properly restore the glenoid arc. Cadaveric specimens within the collection were acquired during the early twentieth century; however, it has been shown that modern populations are slightly larger. Given that this study focused on comparative differences in glenoid and coracoid measurements rather than absolute amounts, the authors do not believe this limitation affects our ultimate conclusions. However, the generalizability of these measurements to a modern population is unknown and warrants further investigation. Lastly, despite the statistically significant differences appreciated in this investigation, the clinical relevancy of these findings warrants further investigation.

Both glenoid and coracoid measurements were significantly different based on sex, with male specimens possessing significantly larger measurements than female specimens. Prior investigations have demonstrated similar findings. Studies by both Saltzmann et al. [32] (23 fresh frozen cadavers; *n* = 17 female and *n* = 6 male) and Rios et al. [30] (60 pairs of skeletal scapulae; *n* = 48 males and *n* = 12 females) reported male specimens to have significantly greater coracoid length, as well as greater coracoid width and thickness when measured from the coracoid tip [32] or the coracoid base [30]. Furthermore, studies by Churchill et al. [13] (172 pairs of skeletal scapulae; *n* = 100 males, *n* = 72 females) and Merrill et al. [26] (184 pairs of skeletal scapulae; *n* = 92 males, *n* = 92 females) reported significantly greater glenoid width measurements in male than in female specimens. Moreover, data from this investigation

Table 2 Measurements of glenoid and coracoid dimensions based on sex

	Males	Females	<i>p</i> value
Total number subjects (specimens)	813 (1626)	181 (362)	–
Mean age (years)	50.5 ± 14.9	45.1 ± 18.0	< 0.001
Mean glenoid width (mm)	29.6 ± 2.1	24.7 ± 1.7	< 0.001
Mean coracoid width (mm)	16.1 ± 1.7	13.3 ± 1.4	< 0.001
Mean coracoid thickness (mm)	9.6 ± 1.2	8.0 ± 1.0	< 0.001
Mean coracoid length (mm)	46.4 ± 3.3	40.5 ± 3.2	< 0.001

Table 3 Measurements of glenoid and coracoid dimension based on age

	Total number subjects (specimens)	Mean glenoid width	Mean coracoid width	Mean coracoid thickness	Mean coracoid length
18–29	230 (115)	26.5 ± 2.7	14.1 ± 1.9	8.8 ± 1.4	43.5 ± 4.4
30–39	306 (153)	27.9 ± 2.7	15.0 ± 2.0	9.2 ± 1.2	44.4 ± 4.0
40–49	456 (228)	28.6 ± 2.3	15.5 ± 1.8	9.4 ± 1.2	45.4 ± 3.6
50–59	446 (223)	29.2 ± 2.5	16.0 ± 1.8	9.4 ± 1.3	46.0 ± 3.7
60–69	336 (168)	29.7 ± 2.7	16.4 ± 1.9	9.5 ± 1.3	46.1 ± 3.7
70+	224 (112)	29.4 ± 2.9	16.3 ± 1.9	9.4 ± 1.4	45.5 ± 4.7
<i>p</i> value	–	< 0.001	< 0.001	< 0.001	< 0.001
95% CI	–	0.048–0.063	0.038–0.049	0.007–0.014	0.034–0.056

confirms findings from previous investigations showing the width of the coracoid to be greater than its thickness [3, 17].

When examined based on race, glenoid width, along with coracoid length and thickness, was significantly larger in Caucasians than in African Americans, while coracoid thickness was significantly greater in African Americans. Previous investigations examining differences based on race have been underpowered and unable to detect significant differences in measured dimensions of the coracoid and glenoid. Using a random assortment of races ($n = 17$ Caucasian males, $n = 32$ African American males, $n = 13$ Caucasian females, $n = 37$ African American females), Ljungquist et al. [24] found no significant differences in coracoid or glenoid dimensions, reporting only that the ratio of glenoid width to glenoid length was significantly larger in Caucasian males when compared to African American males and other ethnicities. Similarly, the investigation by Churchill et al. [13] utilizing 172 pairs of scapulae ($n = 100$ males, $n = 72$ females) from the same osteologic collection used in this investigation found no significant differences in glenoid width, again citing an insufficient number of specimens to detect a difference.

No study in the literature has compared glenoid and coracoid dimensions based on age. Mean values from this analysis were interesting, as no organic etiology was found behind the increasing dimensions appreciated with increasing age at the time of death. Specifically, all specimens with evidence of osteophytes distorting glenoid or coracoid anatomy were excluded, eliminating age-related osteoarthritic changes as a confounding factor. Furthermore, the author performing the measurements was blinded to specimen age,

further minimizing the potential for observer bias. This finding warrants further investigation.

Position of the coracoid, using either the classic Latarjet or the modified Latarjet, provided adequate bone to successfully reconstruct the glenoid in specimens with 20% loss of glenoid width. Meanwhile, specimens with 25% bone loss had adequate bone available for reconstruction using the modified Latarjet technique, while only a small percentage (1.9%) of scapulae did not have adequate bone using the classic technique. Proper restoration of the anteroinferior glenoid is well known to be critical in order to minimize dislocation rates following bony augmentation [8, 10, 27, 36]. To ensure the bone harvested from the coracoid is capable of reconstructing the dimensions of the glenoid surface, pre-operative planning involving radiographs and advanced imaging including CT is routinely utilized for accurate assessment of both coracoid dimensions and glenoid bone loss [2, 4, 6, 12, 21]. The subgroup analysis found that significant differences in the ratio of bone available versus glenoid bone loss are dependent on patient sex, race, and age. While only a small incidence of shortened coracoid dimensions preventing adequate reconstruction of glenoid width was found, pre-operative planning remains essential to ensure sufficient coracoid length and ability to accommodate two screws to minimize non-union [1, 23]. In patients with glenoid bone loss of more than one-third of the glenoid articular surface, the coracoid and associated soft tissues contributing to the “sling effect” may not provide adequate bone for successful reconstruction, necessitating use of alternative donor sites from the iliac crest or distal tibia [19, 24, 28, 29, 39].

Table 4 Glenoid width restoration, classic vs. modified Latarjet technique, based on ratio of bone available/bone loss in setting of 20 and 25% bone loss

		Race		Sex		Age					
		Caucasian	African American	Male	Female	18–29	30–39	40–49	50–59	60–69	70+
20% bone loss	Classic	1.59	1.67	1.63	1.62	1.65	1.65	1.64	1.62	1.60	1.60
	<i>p</i> value	< 0.01		0.80		< 0.01					
	Modified	2.73	2.73	2.73	2.70	2.65	2.69	2.71	2.75	2.77	2.78
	<i>p</i> value	0.88		0.01		< 0.01					
25% bone loss	Classic	1.27	1.34	1.30	1.30	1.32	1.32	1.31	1.29	1.28	1.28
	<i>p</i> value	< 0.01		0.80		< 0.01					
	Modified	2.18	2.18	2.19	2.16	2.12	2.16	2.17	2.20	2.21	2.22
	<i>p</i> value	0.88		0.01		< 0.01					

In conclusion, this investigation represents the largest number of cadaveric specimens used in measuring differences in glenoid and coracoid dimensions based on sex, race, and age. All measured dimensions were significantly larger in males than in females and in Caucasians than in African Americans, except for mean coracoid thickness. All dimensions increased with advancing age at the time of death. Assessment of bone available for reconstruction of glenoid width found both classic and modified Latarjet procedures capable of adequately reconstructing 20% loss of glenoid width, with larger defects more reliably reproduced using the modified technique. Surgeons must be aware of these differences when planning for glenoid reconstruction using the Latarjet technique for patients with bony glenoid deficits and shoulder instability.

Compliance with Ethical Standards

Conflict of Interest: Derrick M. Knapik, MD, Jameson Cumsky, BA, and Joseph E. Tanenbaum, BA, declare that they have no conflicts of interest. James E. Voos, MD, reports being a paid consultant for Arthrex, Stryker, and ConMed Linvatec, outside the submitted work. Robert J. Gillespie, MD, reports being a paid consultant for DJ Orthopaedics and Wright Medical Technology, outside the submitted work.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2013.

Informed Consent: Informed consent was waived from all patients for being included in this study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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