Original Article

The morphometric anatomy of the delto-fulcral triangle: A 3D CT-based reconstruction study

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ABSTRACT

This study introduced the new delto-fulcral triangle (DFT), the first anatomical model of its kind. As seen from the orthopaedician's supraspinatus-outlet view, the antero-superior point of the coracoid process along with the lateral- and posterior-most acromial landmarks form the boundaries of the DFT. Since these osseous scapular landmarks accounted for both dynamic and static stabilisers of the glenohumeral joint, knowledge of the anatomical features of the DFT may prove beneficial to the orthopaedic surgeon. This study thus aimed to investigate the morphometry of the new DFT. The bony surfaces of one-hundred and sixty-nine ($n = 169$) normal and pathological (Omarthrosis and Cuff-Tear Arthropathy) shoulders from the hospital's CT scan database were reconstructed (Mimics[®]: Materialise, Leuven, Belgium). Statistical significance was observed between all three groups for Side 2 (LACPF: distance between most lateral and most posterior points of the acromion) and angles α (angle between sides 1 and 3) and β (angle between sides 1 and 2) of the DFT. It was postulated that although pathological cases present with a smaller lateral acromial distance (LACPF), their lateral acromion landmark is more posteriorly placed from the scapular plane than that of a normal case. As the aspects of the morphometric anatomy of the DFT presented with levels of statistical significance, it may provide a means to evaluate the anatomy of normal and pathological cases. Additionally, the three osseous scapular landmarks that create the DFT are clearly visualised and palpable, therefore they are easily reproducible from both X-ray images and CT scans.

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1. Introduction

The scapula, commonly known as the shoulder blade, is a flat triangular bone situated in the postero-lateral region of the thorax.^{1–3} In addition to the anterior and posterior surfaces, it has superior, medial and lateral borders that are limited by superior, inferior and lateral angles.^{2,3} While the lateral angle is marked by the glenoid cavity for articulation with the humeral head, the scapula also bears three prominent anatomical features, viz. coracoid process anteriorly, the acromion laterally and the spine on the posterior scapular aspect.^{2–4}

As seen from the supraspinatus-outlet view, a characteristic triangle is created from three osseous scapular landmarks,

viz. the antero-superior point of the coracoid process, and the lateral- and posterior-most aspects of the acromion. The present study defined this three-dimensional space as the new delto-fulcral triangle that is formed by the boundaries arising from the three above-mentioned osseous landmarks.

For the orthopaedic surgeon, these three osseous landmarks form a triangle that presents as a window for the evaluation of the subacromial space in cases of impingement.⁵ Additionally, the apical roof of the delto-fulcral triangle accounts for the deltoid muscle trajectory as it descends from the superior scapular aspect to wrap over the humeral head.^{6,7} Furthermore, the three osseous landmarks of this triangle represent both dynamic and static shoulder stabilisers which constitute the coronal and transversal rotator cuff force couples that work collectively to provide a stable fulcrum for glenohumeral motion.^{6,8}

Thus, the aim of this study was to investigate the morphology of the new delto-fulcral triangle.

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2. Materials and methods

In the present study, the Mimics Innovation Suite® software package (Materialise, Leuven, Belgium) was used to retrospectively review and reconstruct the bony surfaces of one-hundred and sixty-nine shoulders ($n = 169$) belonging to the normal (60), omarthrosis (65) and cuff-tear arthropathy (44) groups. The data was extracted from the existing CT scan database at Ghent University Hospital.

Following the placement of a best-fit circle at the inferior glenoid aspect, the origin landmark (O) was placed within the centre of it. The point properties of O were then corrected to that of the native inferior glenoid circle to ensure that it was precisely located. Once the scapular and native inferior glenoid planes were created as planes of reference, a left-handed cartesian coordinate system was incorporated into the stimulation process.^{9,10}

A left-handed cartesian coordinate system was included in the native circular system. As O was defined as the centre of the native inferior glenoid circle, the x-, y- and z-axes were described accordingly.

The left-handed cartesian coordinate system was defined as follows:

- (i) y-axis: plane passing through the origin point that is parallel to the scapular plane
- (ii) x-axis: plane passing through the origin point of the native inferior glenoid circle that is perpendicular to the y-axis and native inferior glenoid plane
- (iii) z-axis: plane passing through the origin point of the native inferior glenoid circle that is perpendicular to the x- and y-axes.

In order to ensure accuracy in the construction of the delto-fulcral triangle, the placement of the three osseous landmarks was as follows:

- (i) Anterior fulcrum: Most antero-superior point of the coracoid process, parallel to the scapular plane¹¹
- (ii) Lateral acromion: Most lateral point of the acromion, parallel to the native inferior glenoid plane
- (iii) Posterior fulcrum: Most posterior point of the acromion, parallel to the scapular plane¹¹

The parameters to be investigated were then computed into the simulation process. These included (Fig. 1a and b):

- (a) Distances of the delto-fulcral triangle
 - Distance between:
 - (i) Anterior fulcrum and Lateral acromion landmarks (Side 1: AFLAC)
 - (ii) Lateral acromion and Posterior fulcrum landmarks (Side 2: LACPF)
 - (iii) Anterior fulcrum and Posterior fulcrum landmarks (Side 3: AFPP)
- (b) Angles within the delto-fulcral triangle
 - a. β – Angle between Sides 1 (AFLAC) and 2 (LACPF)
 - b. δ – Angle between Sides 2 (LACPF) and 3 (AFPP)
 - c. α – Angle between Sides 1 (AFLAC) and 3 (AFPP)
- (c) Area of the delto-fulcral triangle:

The area of the delto-fulcral triangle was expressed through the means of the trigonometric Side-Angle-Side (SAS) formula:

$$\text{Area} = (\text{Side 1})(\text{Side 2})\sin(\text{Included Angle})$$

$$= (\text{AFLAC})(\text{LACPF})\sin(\delta)$$

- (d) Additional distances

Fig. 1. Morphometric parameters. (a) Distances and angles of the Delto-fulcral triangle, and (b) Distances between landmarks of the Delto-fulcral triangle and the inferior glenoid circle.

Key: A, anterior; AF, anterior fulcrum point arising from anterior-most aspect of coracoid process; I, inferior; LAC, lateral acromion point arising from lateral-most aspect of acromion; O, origin of native inferior glenoid circle; P, posterior; PF, posterior fulcrum point arising from posterior-most aspect of acromion; r-radius of inferior glenoid circle; S, superior; SP, scapular plane.

Distance between:

- (i) Lateral acromion landmark and Scapular plane (LACSP)
- (ii) Anterior fulcrum and Origin landmarks (AFO)
- (iii) Posterior fulcrum and Origin landmarks (PFO)
- (iv) Lateral acromion and Origin landmarks (LACO)
- (v) Radius of inferior glenoid circle

Intra-observer error of a single investigator was reduced by performing the simulation process three times for each patient case. In addition, the inter- and intra-observer reliability was assessed for all parameters by calculating the interclass correlation co-efficient (ICC).

Ethical clearance was issued by the relevant institutional review board of Ghent University Hospital.

Statistical analysis employed the use of SPSS version 21.0, specifically the Independent Samples *T*-Test and the Independent Kruskal-Wallis Test. *P* values of less than 0.05 were considered to be statistically significant.

3. Results

The mean distances, angles and area of the delto-fulcral triangle were recorded for all three groups (Fig. 2a–c; Tables 1 and 2). The inter- and intra-observer reliability ranged from good to excellent for both the omarthrosis (ICC: 0.780–0.976) and cuff-tear arthropathy (ICC: 0.763–0.952) groups.¹²

The distance between the anterior fulcrum and lateral acromion landmarks (Side 1 – AFLAC) was observed to be 55.60 ± 5.20 mm, 56.50 ± 6.16 mm and 54.99 ± 5.86 mm in the normal, omarthrosis and cuff-tear arthropathy groups, respectively. In the normal group the distance between the lateral acromion and posterior fulcrum (Side 2 – LACPF) appeared to be 44.15 ± 6.75 mm, while those of the omarthrosis and cuff-tear arthropathy groups were 40.19 ± 7.44 mm and 41.57 ± 5.58 mm, respectively. Moreover, the comparison of the LACPF distance between all three groups yielded a statistically significant *P* value of 0.008. Side 3, which depicted the distance between the anterior and posterior fulcrum landmarks (AFPP), was found to be 77.85 ± 7.75 mm, 76.77 ± 7.34 mm and 76.07 ± 5.28 mm

Fig. 2. Supraspinatus-outlet view of the delto-fulcral triangle in the normal and pathological groups. (a) normal, (b) omarthrosis, and (c) cuff-tear arthropathy.

Key: A, anterior; AF, anterior fulcrum point arising from anterior-most aspect of coracoid process; I, inferior; LAC, lateral acromion point arising from lateral-most aspect of acromion; P, posterior; PF, posterior fulcrum point arising from posterior-most aspect of acromion; S, superior.

in the normal, omarthrosis and cuff-tear arthropathy groups, respectively.

Angle β , enclosed between Sides 1 and 2, was calculated to be $102.31 \pm 4.71^\circ$, $104.65 \pm 5.69^\circ$ and $103.30 \pm 5.99^\circ$ in the normal, omarthrosis and cuff-tear arthropathy groups, respectively. Accordingly, a P value of 0.023 revealed statistical significance for the angle β between all three groups. In the normal group angle δ between Sides 2 and 3 was $44.18 \pm 3.76^\circ$, however in the omarthrosis and cuff-tear arthropathy groups it was $45.18 \pm 5.42^\circ$ and $44.58 \pm 4.66^\circ$, respectively. Although angle α , formed between Sides 1 and 3, was seen to be $33.19 \pm 4.40^\circ$ in the normal groups, it was identified to be $30.17 \pm 5.51^\circ$ and $32.12 \pm 4.87^\circ$ particular to the omarthrosis and cuff-tear arthropathy groups. In addition, a statistically significant P value of 0.002 was recorded for the comparison of angle α between all three groups.

The area of the delto-fulcral triangle was quantified to be $1202.10 \pm 272.29 \text{ mm}^2$, $1087.67 \pm 239.00 \text{ mm}^2$ and $1115.32 \pm 213.27 \text{ mm}^2$ in the normal, omarthrosis and cuff-tear arthropathy groups, respectively.

In addition, complementary distances between the landmarks of the delto-fulcral triangle and the glenoid fossa were investigated (Table 3). The distance between the lateral acromion landmark and the scapular plane (LACSP), which was determined to correspondingly be $8.50 \pm 4.43 \text{ mm}$, $13.74 \pm 6.73 \text{ mm}$ and $13.09 \pm 5.33 \text{ mm}$ in the normal, omarthrosis and cuff-tear arthropathy groups; yielded a statistically significant difference (P value = 0.000) upon comparison between the groups. In the normal group, the radius of the inferior glenoid circle appeared to be $14.81 \pm 1.63 \text{ mm}$, whereas that of the omarthrosis and cuff-tear arthropathy groups were $14.99 \pm 1.76 \text{ mm}$ and $13.54 \pm 1.63 \text{ mm}$, respectively. Accordingly, a statistically significant difference of 0.000 was recorded between the radius of the inferior glenoid circle and the normal and pathological groups. The distances between both fulcrum landmarks and the origin point (O) were recorded in the normal (AFO: $38.76 \pm 4.62 \text{ mm}$; PFO: $38.45 \pm 4.98 \text{ mm}$), omarthrosis (AFO: $35.87 \pm 5.47 \text{ mm}$; PFO: $40.18 \pm 4.49 \text{ mm}$) and cuff-tear arthropathy (AFO: $34.74 \pm 4.55 \text{ mm}$; PFO: $40.05 \pm 3.74 \text{ mm}$) groups. A level of statistical significance (P value = 0.000) was recorded between the AFO distance and the

Table 1
Distances of the Sides of the delto-fulcral triangle in the Normal and Pathological groups.

Parameter	Distance (mm)		
Group	Side 1 (AFLAC): anterior fulcrum & lateral acromion	Side 2 (LACPF): lateral acromion & posterior fulcrum	Side 3 (AFPF): anterior fulcrum & posterior fulcrum
Normal	55.60 ± 5.20	44.15 ± 6.75	77.85 ± 7.75
Omarthrosis	56.50 ± 6.16	40.19 ± 7.44	76.77 ± 7.34
Cuff-tear arthropathy	54.99 ± 5.86	41.57 ± 5.58	76.07 ± 5.28
P value	0.402	0.008*	0.472

AFPF, distance between anterior-most aspect of coracoid process and posterior-most aspect of acromion.

LACPF, distance between lateral-most aspect of acromion and posterior-most aspect of acromion.

AFLAC, distance between anterior-most aspect of coracoid process and lateral-most aspect of acromion.

* Significant P value.

Table 2
Angles and Area of the delto-fulcral triangle in the Normal and Pathological groups.

Parameter	Angle between: (degrees $^\circ$)			Area of Delto-fulcral triangle (mm 2)
Group	β : Sides 1 & 2	δ : Sides 2 & 3	α : Sides 1 & 3	
Normal	102.31 ± 4.71	44.18 ± 3.76	33.19 ± 4.40	1202.10 ± 272.29
Omarthrosis	104.65 ± 5.69	45.18 ± 5.42	30.17 ± 5.51	1087.67 ± 239.00
Cuff-tear arthropathy	103.30 ± 5.99	44.58 ± 4.66	32.12 ± 4.87	1115.32 ± 213.27
P value	0.023*	0.730	0.002*	0.085

* Significant P value.

Table 3

Distances between landmarks of the Delto-fulcral triangle and the inferior glenoid circle in the Normal and Pathological groups.

Parameter Group	Distance between: (mm)				
	Lateral acromion & Scapular plane (LACSP)	Anterior fulcrum and origin (AFO)	Posterior fulcrum and origin (PFO)	Radius of Inferior Glenoid Circle (r)	Lateral acromion and origin (LACO)
Normal	8.50 ± 4.43	38.76 ± 4.62	38.45 ± 4.89	14.81 ± 1.63	34.21 ± 2.87
Omarthrosis	13.74 ± 6.73	35.87 ± 5.47	40.18 ± 4.49	14.99 ± 1.76	28.43 ± 2.44
Cuff-Tear Arthropathy	13.09 ± 5.33	34.74 ± 4.55	40.05 ± 3.74	13.54 ± 1.63	21.41 ± 1.72
P Value	0.000 [*]	0.000 [*]	0.068	0.000 [*]	0.835

AFO, distance between anterior-most aspect of coracoid process and origin of native inferior glenoid circle.

LACO, distance between lateral-most aspect of acromion and origin of native inferior glenoid circle.

LACSP, distance between lateral acromion landmark and scapular plane.

PFO, distance between posterior-most aspect of acromion and origin of native inferior glenoid circle.

r, radius of inferior glenoid circle.

^{*} Significant P value.

study groups. The distance between the lateral acromion and origin (LACO) was found to be 34.21 ± 2.87 mm, 28.43 ± 2.44 mm and 21.41 ± 1.72 mm in the normal, omarthrosis and cuff-tear arthropathy groups, respectively.

4. Discussion

This study introduced the delto-fulcral triangle, which is the first anatomical model of its kind, represented the supraspinatus outlet that is limited inferiorly by the humeral head. The relative mean distances, angles and area of the delto-fulcral triangle were investigated in the normal and two pathological groups.

The distance between the anterior fulcrum and lateral acromion landmarks (Side 1 – AFLAC) appeared largest in the omarthrosis group but smallest in the cuff-tear arthropathy group. Although the distances pertaining to Sides 2 and 3 (LACPF and AFPF) were greatest in the normal group, the Sides 2 and 3 (LACPF and AFPF) were lowest in the omarthrosis and cuff-tear arthropathy groups, respectively, thus denoting the absence of pathology. Subsequently, the comparison of the LACPF distance between all three groups revealed a statistically significant difference indicating that the lateral acromial length is markedly different in the normal and pathological groups. Since Side 1 (AFLAC) was larger than Side 2 (LACPF) and these sides corresponded to the anterior and posterior openings of the supraspinatus outlet, it was evident that the anterior opening of the supraspinatus outlet is larger in both the normal and pathological groups. Despite exhibiting lesser variability, Side 2 (LACPF) which also depicted the postero-lateral acromial length, was markedly shorted in this study and may explain its role as a precursor to the ensuing pathology.¹³

Angles β (between Sides 1 and 2) and δ (between Sides 2 and 3) were both higher in the omarthrosis group but smaller in the normal group. As angle β corresponds to the apical aspect of the roof of the delto-fulcral triangle, it may be postulated from the statistically significant P value yielded for the comparison of it between all three groups, that a high β angle is typical to the omarthrosis group. On the contrary, angle α (between Sides 1 and 3) was found to be largest in the normal group and lowest in omarthrosis group. This observation was quite the opposite to that identified in angles β and δ , however the statistically significant P value that was recorded for the comparison of angle α may indicate that this angle is generally larger in the normal group. Therefore, the larger α angle coupled with the larger AFLAC distance may allude to the fact that the anterior opening of the supraspinatus outlet is wider than that of the posterior aspect, hence providing more room for the supraspinatus muscle-tendon complex to move freely thus reducing the risk of pathology. In addition to the larger anterior opening (AFLAC), which also depicted the opening wedge of the coraco-acromial ligament, the levels of significance yielded for angles β (between Sides 1 and 2) and α (between Sides 1 and 3)

may substantiate for the success of acromioplasty. Since all three above-mentioned angles show two trends that have a clear tendency towards the high in the normal or the omarthrosis groups, quantification of these angles may provide a means to evaluate normal and pathological cases.

The delto-fulcral triangle in all groups revealed unequal sides, hence portrayed a scalene triangle. Although the area of the delto-fulcral triangle was greatest in the normal group and smallest in the omarthrosis group, the P value of 0.085 revealed that the distribution of the area was relatively similar across all three groups.

In view of the statistical significance recorded for the LACPF distance, the distance between the lateral acromion landmark and scapular plane (LACSP) was relatively larger in the omarthrosis and cuff-tear arthropathy groups than that of the normal group. While the LACPF distance was largest in the normal group, the lateral acromion landmark was seen to situated posterior to the scapular plane in all groups, with the distance between them distinctively increased in the omarthrosis and cuff-tear arthropathy groups. This finding was further verified by the statistically significant difference that was recorded for the comparison of the LACSP distance between all three groups indicating that although pathological cases present with a smaller postero-lateral acromial distance (LACPF), their lateral acromion landmark is more posteriorly placed from the scapular plane than that of a normal case. Furthermore, the disequilibrium of the LACSP distance that was marked by a 5 mm spread between the normal and pathological groups, suggested that the deltoid muscle is not equilibrated in the body of pathological cases. However, the existence of such disequilibrium, due to the position of the scapular plane, necessitates two ways of escape, viz. postero-inferior escape in cases of omarthrosis and antero-superior escape in cases of cuff-tear arthropathy.

Although the PFO distance was larger than the AFO distance, the AFO distance was relatively larger in the normal group. The level of statistical significance recorded for the comparison of AFO distance with the study groups, may account for the longer AFO distance in the normal group, thus confirming an adapting nature. The increased radius of the inferior glenoid circle that was manifested by the omarthrosis group, correlated with a wider more angulated roof of the delto-fulcral triangle. This would depict a larger coverage over the humeral head and was further substantiated by a statistically significant difference of 0.000. In addition, the normal group presented with the lateral acromion landmark situated most posterior to the origin of the inferior glenoid circle, thereby reflecting a larger anterior opening of the supraspinatus outlet.

Considering that statistical significance was observed for one side and two angles of the delto-fulcral triangle in this study, the placement of the osseous delto-fulcral landmarks was based on

scientific reasoning that evolved from an in depth review of previous literature in order to sculpt the best-fitting morphology of the delto-fulcral triangle.^{6,8,11,14–19} Anatomically, the three sides that create this triangle in the typical supraspinatus-outlet view are easily obtainable from both X-ray images and CT scans because the three osseous scapular landmarks are clearly visualised.

Side 1 (AFLAC), arising from the antero-superior aspect of the coracoid process and ending at the lateral acromion, represented the ligamentous attachment of the coraco-acromial ligament that spans the area of the coraco-acromial arch, over which the deltoid muscle passes towards its humeral insertion at the deltoid tuberosity.^{3,20}

Although Edelson and Taitz²⁰ drew a parallelism between the architectural changes of the coraco-acromial arch and humeral impingement, in this study the distribution of the AFLAC distance was the same across all three groups with no significant difference in the overall area of the delto-fulcral triangle.

Side 2 (LACPF), which originates at the lateral-most acromion and ends at the posterior-most aspect of it, corresponded to the postero-lateral aspect of the acromion as well as accounted for the inflection point as the acromion modulates from lateral to posterior. Inevitably, the extent from lateral acromion landmark to the posterior acromion landmark represents the lateral acromial length.

This lateral acromial length was seen to be longest in the normal group of the current study and according to Ciochon and Corruccini,²¹ the increase in this length is linked to the evolutionary process of brachiation as the quadruped eventually developed into the biped, thus required adaptation of certain osseous structures necessary for feeding and locomotion. Moreover, the modified extension of the lateral acromial length accommodated for the attachment of the deltoid muscle which then counterbalanced the comparative weakness of the supraspinatus muscle.^{21,22} This was consistent with the anatomical findings of Sakoma et al.²³ who reported that the anterior, middle and posterior deltoid portions originated from the respective aspects of the lateral acromial length. Furthermore, in the recent study conducted by Viehöfer et al.,²⁴ the lateral acromial length was reported to cause a change in the size of the deltoid moment arm and ultimately glenohumeral stability.

In addition, the inclusion of the lateral acromion landmark in Sides 1 and 2 was due to its association with degenerative changes in rotator cuff tears and omarthrosis.¹⁶

Side 3 (AFPF), which commences at the antero-superior aspect of the coracoid process and passes posteriorly to posterior-most aspect of the acromion is inevitably the fulcrum axis, hence the referral of these landmarks as the anterior and posterior fulcrum points, respectively.^{11,18} Both these distally-placed landmarks are common body-surface landmarks used in shoulder arthroscopy as they lie approximately parallel to the glenoid plane.^{11,18} Although the AFPF distance was marginally larger in the normal group of this study, the *P* value of 0.472 showed consistency in the distribution of this distance across all three groups. The AFPF distance also constitutes the widest attachment of the deltoid and the broadest lever arm in the transversal plane as the muscle arches over the scapula during its descent to the humeral insertion.

Although this study accounted for the trajectory of the deltoid muscle and its osseous origin sites, the anterior aspect of the lateral-third of the clavicle was excluded (Standring et al., 2016)³. While this may present as a limitation, the study conducted by Van Tongel et al.²⁵ concluded that glenohumeral functionality was not greatly compromised in cases of congenital or acquired, complete or fractional absence of the clavicle. Therefore, the model of the delto-fulcral triangle in the present

study considered both dynamic (deltoid muscle) and static (bone: scapula; ligament: coracoacromial ligament) stabilising structures of the glenohumeral joint.²⁶ Furthermore, through the use of 3D software, the osseous scapular anatomy was more accurately depicted.

5. Conclusion

The present study designed and introduced the anatomical delto-fulcral triangle which takes the appearance of a scalene triangle. Since levels of statistical significance were recorded for the comparison of two angles and one side between all three groups, knowledge of the morphometry of the delto-fulcral triangle may benefit the orthopaedic surgeon during surgical repair in and around the glenohumeral joint. The focus and incorporation of palpable osseous scapular landmarks may assist the anatomist and anthropologist to further analyse and provide updated data on the respective evolutionary changes.

Conflicts of interest

The authors have none to declare.

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References

1. Faiz O, Moffat D. *Anatomy at a glance*. 2002.
2. Moore KL, Dalley AF, Agur AM. *Clinically oriented anatomy*. Lippincott Williams & Wilkins; 2013.
3. Standring S. *Gray's anatomy: the anatomical basis of clinical practice*. 40th ed. Spain: Elsevier Ltd.; 2016.
4. Insull P. Clinical anatomy: applied anatomy for students and junior doctors -by Harold Ellis. *ANZ J Surg*. 2007;77(10):911–912.
5. Clifford R. *Wheelless' textbook of orthopaedics*. Brooklandville, Maryland: Data Trace Internet Publishing; 1996.
6. Gagey O, Hue E. Mechanics of the deltoid muscle: a new approach. *Clin Orthop Relat Res*. 2000;375:250–257.
7. Bois AJ, Fening SD, Polster J, Jones MH, Miniaci A. Quantifying glenoid bone loss in anterior shoulder instability reliability and accuracy of 2-dimensional and 3-dimensional computed tomography measurement techniques. *Am J Sports Med*. 2012;26(September). 0363546512458247.
8. Veeger HE, Van Der Helm FC, Van Der Woude LH, Pronk GM, Rozendal RH. Inertia and muscle contraction parameters for musculoskeletal modelling of the shoulder mechanism. *J Biomech*. 1991;24(7):615–629.
9. Saller K. *Systematische Anthropologie A. Somatische Anthropologie. Lehrbuch der Anthropologie*. Stuttgart: G Fisher; 1957:528–532.
10. De Wilde LF, Verstraeten T, Speckaert W, Karelse A. Reliability of the glenoid plane. *J Should Elb Surg*. 2010;19(3):414–422.
11. Braunstein V, Korner M, Brunner U, Mutschler W, Biberthaler P, Wiedemann E. The fulcrum axis: a new method for determining glenoid version. *J Should Elb Surg*. 2008;17(5):819–824.
12. Jaxsens M, Van Tongel A, Henninger HB, De Coninck B, Mueller AM, De Wilde L. A three-dimensional comparative study on the scapulohumeral relationship in normal and osteoarthritic shoulders. *J Should Elb Surg*. 2016.
13. Neer CS. Replacement arthroplasty for glenohumeral osteoarthritis. *J Bone Joint Surg Am*. 1974;56(1):1–3.
14. Ackland DC, Pak P, Richardson M, Pandey MG. Moment arms of the muscles crossing the anatomical shoulder. *J Anat*. 2008;213(4):383–390.
15. Steenbrink F, De Groot JH, Veeger HE, van der Helm FC, Rozing PM. Glenohumeral stability in simulated rotator cuff tears. *J Biomech*. 2009;42(11):1740–1745.
16. Moor BK, Bouaicha S, Rothenfluh DA, Sukthankar A, Gerber C. Is there an association between the individual anatomy of the scapula and the development of rotator cuff tears or osteoarthritis of the glenohumeral joint? *Bone Joint J*. 2013;95(7):935–941.
17. Gerber C, Snedeker JG, Baumgartner D, Viehöfer AF. Supraspinatus tendon load during abduction is dependent on the size of the critical shoulder angle: a biomechanical analysis. *J Orthop Res*. 2014;32(7):952–957.
18. Le SV, Conrad B, Wright TW. Application of the fulcrum axis to estimate the central scapular axis. *J Should Elb Surg*. 2014;23(8):1143–1149.
19. Ghafurian S, Galdi B, Bastian S, Tan V, Li K. Computerized 3D morphological analysis of glenoid orientation. *J Orthop Res*. 2015.

20. Edelson JG, Taitz C. Anatomy of the coraco-acromial arch. Relation to degeneration of the acromion. *Bone Joint J.* 1992;74(4):589–594.
21. Ciochon RL, Corruccini RS. The coraco-acromial ligament and projection index in man and other anthropoid primates. *J Anat.* 1977;124(Pt 3):627.
22. Voisin JL, Ropars M, Thomazeau H. The human acromion viewed from an evolutionary perspective. *Orthop Traumatol: Surg Res.* 2014;100(8):S355–S360.
23. Sakoma Y, Sano H, Shinozaki N, et al. Anatomical and functional segments of the deltoid muscle. *J Anat.* 2011;218(2):185–190.
24. Viehöfer AF, Snedeker JG, Baumgartner D, Gerber C. Glenohumeral joint reaction forces increase with critical shoulder angles representative of osteoarthritis—a biomechanical analysis. *J Orthop Res.* 2015.
25. Van Tongel A, Piepers I, De Wilde L. The significance of the clavicle on shoulder girdle function. *J Should Elb Surg.* 2015;24(9):e255–e369.
26. Wilk KE, Arrigo CA, Andrews JR. Current concepts: the stabilizing structures of the glenohumeral joint. *J Orthop Sports Phys Ther.* 1997;25(6):364–379.