



# Examining changes in acromial morphology in relation to spurs at the anterior edge of acromion

Abdulrahman Alraddadi<sup>1,2</sup> · Abdulmenem Alashkham<sup>1,3</sup> · Clare Lamb<sup>1</sup> · Roger Soames<sup>1</sup>

Received: 13 June 2018 / Accepted: 22 November 2018 / Published online: 27 November 2018  
© Springer-Verlag France SAS, part of Springer Nature 2018

## Abstract

**Background** Although acromial morphology is classified as flat, curved, and hooked, whether the morphology is primary or acquired is debated. There have been no investigations on the effect of acromial spurs on acromial morphology. This study therefore aimed to evaluate acromial morphology in relation to spur formation at the anterior edge of the acromion.

**Materials and Methods** Acromial morphology was investigated in 40 scapulae taken from 20 cadavers (10 male and 10 female), with a median age of 82 years (range 62–97 years). Ink prints of the anteroposterior aspect of the acromion were used to evaluate acromial slope angle and curvature height in relation to spur incidence, length, and shape at the anterior edge of the acromion.

**Results** Differences were observed in acromial morphology and acromial curvature in relation to acromial spurs (incidence, size, and shape). A hooked acromion was observed as a primary structure in 25% of specimens, which increased to 43% when acromial spurs were involved. No differences were observed in relation to sex or side, while a significant correlation was observed between acromial curvature and the age of the specimens.

**Conclusion** Acromial spurs increase acromial curvature and therefore change acromion morphology. Nevertheless, it is concluded that a hooked acromion occurs as a primary formed structure.

**Level of evidence** Basic science study, anatomy, cadaver dissection.

**Keywords** Acromial slope · Acromial curvature height · Acromial morphology · Acromial spur · Shoulder degenerative changes

## Introduction

The morphology of the acromion has been classified into three types: flat, curved, and hooked [6]. Bigliani et al. [6] also used the acromial slope angle to determine the anteroposterior curvature of the acromion. Previous studies have

reported that shoulders with full-thickness rotator cuff tears had a significant incidence of a hooked acromion and a greater acromial slope angle [6, 8, 12, 13, 26, 32, 34, 35, 39]. Contact between the acromion and humeral head has also been detected in shoulders with a hooked acromion [14]. In contrast, no relationship between rotator cuff tears and a hooked acromion or difference in acromial slope has been observed [3, 4, 17, 20, 21, 38].

The underlying source of a hooked acromion is debated, with two contradictory theories put forward to explain its formation: the first suggests that a hooked acromion is congenital [25, 31], while the second proposes that an acromial spur leads to an acquired or developmental hooked acromion. The second theory is based on three factors: (1) tensile forces applied to the acromion by the coracoacromial ligament [31], (2) degenerative changes associated with aging [18, 33, 37, 38] and (3) misinterpretation regarding the formation of an acromial spur [9–12, 15, 30].

✉ Abdulrahman Alraddadi  
aalraddadi.2012@gmail.com; raddadia@ksau-hs.edu.sa

<sup>1</sup> Centre for Anatomy and Human Identification, School of Science and Engineering, University of Dundee, Dundee, UK

<sup>2</sup> Department of Basic Medical Sciences, College of Medicine-Riyadh, King Saud bin Abdulaziz University for Health Sciences, King Abdulaziz Medical City, Ministry of National Guard Health Affairs, Mail Code 3127, P.O. Box 3660, Riyadh 11481, Kingdom of Saudi Arabia

<sup>3</sup> Centre for Anatomy, School of Biomedical Sciences, University of Edinburgh, Edinburgh, UK

A higher incidence of acromial spurs has been reported in shoulders with a hooked acromion than in other acromial types [15, 22, 26, 28, 29]. In contrast, others [25, 31] have reported no relationship between the incidence of an acromial spur and acromial morphology. Edelson and Taitz [10] suggest that the formation of an acromial spur increases the length of the acromion, therefore changing its morphology. However, there appears to be no study to date which has investigated changes in acromial morphology with respect to the presence of acromial spurs. This study therefore evaluated the geometric curvature of the acromion in relation to the formation of a spur at its anterior edge.

## Materials and methods

Acromial morphology was evaluated in 20 pairs of dry scapulae from 10 male and 10 female cadavers, with a median age of 82 years (range 62–97 years). A pilot study was conducted to calculate sample size needed using OpenEpi software, Version 3. The required sample size for the current study was 26 scapulae with mean difference in the acromial slope mean of  $8^\circ$  at a 5% level of significance with a power of 80%.

Acromial curvature was determined in two ways: acromial slope angle and the height of acromion curvature. Bigliani et al. [6] described acromial slope angle as the angle between two lines connecting the anterior and posterior ends of the acromion interconnecting at the midpoint on the inferior acromion. Edelson and Taitz [10] described the height of the acromial curvature as the maximum height above a straight line drawn between the ends of the acromion (Fig. 1).



**Fig. 1** Sagittal view of scapula shows the method used to measure the lateral acromial curvature parameters: acromial slope angle (A) and acromial curvature height (B)

The current study measured acromial curvature parameters by taking an ink print of the lateral aspect of the acromion. Nine prints were taken from each acromion before selecting the best three and calculating the mean values from which to evaluate acromial morphology. Acromial curvature parameters were measured manually using a goniometer taking into consideration the length of the acromial spur at the anterior edge of the acromion. In addition, the original (primary) acromial curvature parameters were measured in shoulders with acromial spurs to eliminate the spur length at the anterior edge of acromion (Fig. 2). The length of acromion and spur was measured using standard digital calipers.

Acromial morphology was classified according to Toivonen et al. [34] using acromial slope into flat ( $0^\circ$ – $12^\circ$ ), curved ( $12^\circ$ – $27^\circ$ ) and hooked ( $> 27^\circ$ ). Spurs at the anterior edge of the acromion were classified according to their size [27] and shape [19]: spur length was classified as small ( $< 5$  mm), medium (5–10 mm) and large ( $> 10$  mm). Spurs were also classified according to their orientation with respect to the anterior edge of the acromion into straight (traction) spurs and curved (claw) spurs.

The collected data were analyzed using IBM SPSS statistical 21.0 software, with  $P < 0.050$  considered as being statistically significant. The collected data showed normal distribution and equal variance, therefore parametric tests, such as t-test (independent and paired samples), one way ANOVA and Pearson Chi square tests, were conducted to determine differences and relationships between acromial curvature and the presence of an acromial spur. Interobserver



**Fig. 2** Sagittal view of scapula shows the primary (original) acromial curvature in scapula with acromial spur. The curved line extends between the anterior tip of spur (A) and the posterior end of acromion (B). (C) represents the lateral acromial curvature including spur length (A, B). The primary curvature of acromion is explained by the curved line extending from the anterior edge of acromion (B) to the posterior end of the acromion (C)

and intraobserver tests were carried out at the beginning of the study to assess the reliability of the measurements taken.

## Results

The interobserver and intraobserver tests both revealed high intercorrelation coefficients in the measurements taken (Cronbach's  $\alpha = 0.987$ ); consequently there was high reliability in the measurements taken.

Acromial curvature parameters are shown in Table 1 in relation to categorical data. Descriptive statistic showed that the overall mean of acromial slope was  $27 \pm 6$  (range  $12^\circ$ – $45^\circ$ ) and the acromial height was  $6 \pm 2$  (range 3–9 mm). A significant correlation ( $P = 0.001$ ) between acromial slope and acromial height was observed ( $R = 0.8$ ). The mean length of the acromion was  $50.75 \pm 7.4$  mm. There was a significant correlation ( $P < 0.050$ ) between the acromial length and acromial curvature parameters (slope:  $R = 0.4$ , height:  $R = 0.7$ ). With respect to age, a significant correlation ( $P < 0.050$ ) was observed between age and the acromial curvature parameters (slope:  $R = 0.3$ , height:  $R = 0.3$ ). However, in relation to side and sex, statistical analysis showed no significant difference in the acromial curvature parameters ( $P > 0.050$ ).

Acromial spurs were observed at the anterior edge of the acromion in 25 (63%) scapulae with a mean length of  $6 \pm 4$  mm (Table 2). Concerning spur incidence, acromiae were categorized into two groups: those with spurs and those without. Acromiae with spurs had higher acromial curvature parameters than those without ( $P = 0.003$ ,  $P < 0.001$ , respectively). In acromiae with spurs, the original acromial curvature parameters were less than when spurs were considered ( $P < 0.001$ ). However, there was no difference in acromial curvature parameters between acromiae without

**Table 1** Mean and associated standard deviations of acromial curvature parameters (slope and height) in relation to side, sex, and acromial shape

Factors	Acromial slope ( $^\circ$ )	Acromial height (mm)
Total mean	$27 \pm 6$	$6 \pm 2$
Side		
Right (20)	$26 \pm 6$	$5 \pm 2$
Left (20)	$27 \pm 7$	$6 \pm 2$
Sex		
Male (20)	$28 \pm 6$	$6 \pm 2$
Female (20)	$25 \pm 6$	$5 \pm 1$
Acromial shape		
Straight (1)	$12 \pm 0$	$3 \pm 0$
Curved (22)	$23 \pm 3$	$5 \pm 1$
Hooked (17)	$32 \pm 4$	$7 \pm 1$

**Table 2** Mean and associated standard deviations of acromial curvature parameters (slope and height) in relation to spur incidence, spur size, and spur shape

Factors	Acromial slope ( $^\circ$ )	Acromial height (mm)
Spur incidence		
No spur (15)	$23 \pm 5$	$4 \pm 1$
With spurs (25)	$29 \pm 6$	$6 \pm 2$
Original (25)	$23 \pm 6$	$4 \pm 2$
Spur size		
Small (11)	$27 \pm 6$	$6 \pm 2$
Medium (8)	$30 \pm 6$	$6 \pm 1$
Large (6)	$31 \pm 8$	$7 \pm 2$
Spur shape		
Straight (10)	$25 \pm 4$	$5 \pm 1$
Curved (15)	$32 \pm 5$	$7 \pm 1$

spurs and the original acromial curvature in those with spurs ( $P > 0.050$ ).

Acromial spurs were classified as small ( $< 5$  mm) observed in 11 (27%) scapulae, medium (5–10 mm) observed in 8 (20%) scapulae, and large ( $> 10$  mm) observed in 6 (15%) scapulae. Comparing acromial curvature parameters using this classification showed significant differences ( $P < 0.050$ ). With respect to acromial slope, acromiae with large and medium spurs had a greater angle than those without spurs. However, there was no difference in acromial slope between the three groups of spur size, as well as between acromiae with small spurs and those without spurs ( $P > 0.050$ ). With respect to acromial curvature height, acromiae with large spurs had a higher curvature than other spur types and those without spurs ( $P < 0.050$ ). On other hand, acromiae without spurs had a lower curvature than those with different sized spurs ( $P < 0.010$ ). There was no difference in acromial curvature height between acromiae with medium and small spurs ( $P = 0.962$ ).

Anterior acromial spurs were also classified, according to their orientation, into straight (traction) spurs observed in 10 (25%) scapulae and curved (claw) spurs observed in 15 (38%) scapulae. Comparing acromial curvature parameters with the shape of the spur showed significant differences ( $P < 0.001$ ). Acromiae with curved spurs had larger slopes than those without ( $P < 0.001$ ) and those with straight spurs ( $P = 0.002$ ). However, there was no difference in slope between acromiae with straight spurs and those without ( $P = 0.424$ ). In addition, acromiae with curved spurs had a higher acromial curvature than those without ( $P < 0.001$ ) and those with straight spurs ( $P = 0.004$ ). Acromiae with straight spurs also had a higher acromial curvature than those without ( $P = 0.022$ ).

Using the classification of Toivonen et al. [34], different acromial shapes were observed before and after including

spur length at the anterior edge of acromion. A hooked acromion was observed in 17 (43%) of scapulae; however, there were a higher number of scapulae with a curved acromion ( $n=22$ , 55%). A flat acromion was observed in only one scapula ( $n=1$ , 2%). Comparing acromial curvature parameters in relation to acromial shapes showed a significant difference ( $P<0.001$ ). Hooked acromiae had a higher acromial slope and height than curved and flat acromiae, furthermore curved acromiae had a higher slope and height than flat acromiae ( $P<0.001$ ).

With respect to the primary morphology of the acromion, there was lower incidence of hooked acromiae ( $n=10$ , 25%) compared to those when spurs and higher incidences of curved and flat acromiae ( $n=28$ , 70%;  $n=2$ , 5%), respectively. Thus, formation of spurs at the anterior edge of acromion changed 7 (23%) flat and curved acromiae into hooked acromiae; all 7 changes involved curved spurs. In addition, a higher incidence of acromial spurs was detected in hooked acromiae ( $n=14$ , 82%). Most of these spurs were curved ( $n=12$ , 86%), while a curved acromion had an incidence of a straight spur ( $n=8$ , 73%).

## Discussion

The morphology of the acromion can be classified into flat, curved, and hooked [6], with a significant correlation identified between the acromial slope and type of acromion [4, 34]. Bigliani et al. [6] reported acromial slope in relation to acromial morphology as  $13.1^\circ$  in flat acromiae,  $26.9^\circ$  in curved acromiae and  $26.7^\circ$  in hooked acromiae. However, both Toivonen et al. [34] and Balke et al. [4] have reported higher slope angles in hooked acromiae. Tuite et al. [35] reported a mean slope of  $25^\circ$  (range  $8^\circ$ – $42^\circ$ ), with Toivonen et al. [34] also reporting a similar range ( $5^\circ$ – $42^\circ$ ); however, Alobaidy et al. [1] reported a greater slope angle ( $49^\circ$ , range  $27^\circ$ – $69^\circ$ ). In addition, no difference has been reported previously in acromial slope in relation to sex or side [1, 35].

The present study evaluated acromial slope angle considering spurs formed at the anterior edge of the acromion. The measured angles were comparable to those previously reported [4, 6, 34, 35], but less than that of Alobaidy et al. [1], who measured slope as the angle between two intersecting lines connecting the superior and inferior points at the anterior and posterior ends of the acromion.

Several studies have suggested that changes in acromial morphology or the formation of a hooked acromion is a result of degenerative change with aging [18, 33, 37, 38]. In contrast, others have reported no relationship between the shape of the acromion and slope or age [4, 5, 15, 25, 28, 35, 36]. A correlation between acromial curvature and age in acromiae with spurs was observed in the current study. This correlation may result from a significant association

between spur incidence and age as reported previously [19, 27]. Thus, an acromial spur is a degenerative change and could be responsible for the reported relationship between age and acromial morphology.

Agreeing with Edelson and Taitz [10], the current study observed a correlation between the length of the acromion and acromial curvature. However, a higher correlation was observed after the spur length was considered for both acromion slope and height. In addition, there was also a correlation between acromial slope and acromial height. Therefore, changes in the length of the acromion may change acromial morphology.

The current study found that an acromial spur can change the morphology and curvature of the acromion. Considering the incidence of acromial spurs, their length and shape showed a greater acromial slope and curvature height, as well as a different acromial morphology, than those of the primary acromion. In agreement with previous studies [15, 22, 26, 28, 29], the current study observed a high incidence of acromial spurs in hooked acromiae; however, only curved spurs were found to have a significant role in changing the primary morphology of the acromion. The origin of different spur shapes at the anterior edge of the acromion in the present study could not be identified, thus no explanation can be offered for the observed morphology or angulation of the acromion.

Previous studies have suggested misinterpretation in the formation of an acromial spur with respect to a hooked acromion [9–12, 15, 30]. The present study investigated acromion morphology before and after considering the presence of an acromial spur. The results showed that hooked acromiae were present in 25% of specimens, increasing to 43% after the inclusion of an acromial spur. Thus, the current study supports previous studies [25, 31] that a hooked acromion is a congenital manifestation: the formation of an acromial spur may increase acromial curvature and lead to a hooked acromion.

Previous studies have reported a difference in acromial slope angle in relation to rotator cuff tears and shoulder impingement syndrome [4, 6, 35]. Shoulders with rotator cuff tears have been reported to have a higher incidence of acromial spurs than those with intact rotator cuff tendons [6, 16, 23, 34]. Neer [24] observed rotator cuff tears and acromial spur formation in the advanced stage of shoulder impingement syndrome. The difference in acromial slope between shoulders with rotator cuff tears and those with intact rotator cuff tendon may therefore be caused by the formation of an acromial spur in shoulders with rotator cuff tears.

The current study may be criticised for not considering the medial part of the acromion and using a primitive technique such as ink printing. The study inspected the morphology of the acromion objectively based on the acromion slope

[34] and height [10] which is usually measured from the lateral edge of the acromion in the outlet-view [4]. Furthermore, acromial spurs usually develop within the anterolateral band of the coracoacromial ligament [11]. The current study found that spurs mainly developed at the anterolateral edge of the acromion, but that large spurs may extend medially. In contrast, the medial edge of acromion has not been considered in previous studies discussing acromial morphology and commonly shows acromioclavicular osteophytes [10]. At the time of 3D evaluation, using ink prints may be considered a limitation in the current study. However, this technique was compatible to specimens used in this study which were dry scapulae. Furthermore, using an ink printing technique was required to determine precisely the incidence and size of the spur, as well as to distinguish hooked acromia from those with spurs.

There is a lack of evaluation of acromial curvature height in the literature, with it not being reported even in studies which have described it [9]. In addition, there is confusion between acromial slope and acromial tilt angle, with the latter measuring the acromial inclination angle in relation to the coracoid process [2, 7, 20]. The limitation of the present study is the high age range of the specimens examined. However, such specimens enabled the investigation of the effect of an acromial spur on the morphology of the acromion. Future studies should investigate the effect of acromial spurs on acromion morphology in young individuals, as well as in those with rotator cuff tears.

## Conclusion

The current study investigated the effect of an anterior acromial spur on acromial morphology in dry scapulae. Acromia with spurs had a larger acromial curvature than those without. The size and shape of acromial spurs also appear to have an influence on acromial morphology. Acromia with large (> 10 mm) and curved spurs showed a higher acromial curvature than other types. In addition, 25% of acromia were found to have a primary hook shape. However, more hooked acromia were identified after the formation of a spur was considered. It appears, therefore that the presence of an acromial spur can change significantly the morphology of the acromion.

**Acknowledgements** Special thanks to the Centre for Anatomy and Human Identification (CAHID) for providing a professional environment to enable this study to be undertaken, and to those who donated their bodies for medical education and research.

**Author contributions** AA: data collection, analysis, and interpretation, and manuscript writing; AA: data collection; RS and CL: study supervision and manuscript writing.

**Funding** A. Alraddadi received funding from King Saud bin Abdulaziz University for Health Sciences.

## Compliance with ethical standards

**Ethical approval** As the study was conducted on cadaveric material relevant consent had been obtained at the time of body donation in accordance with the Human Anatomy (Scotland) Act 2006.

**Informed consent** Obtained prior to and at the time of body donation.

**Conflict of interest** None of the authors have any conflict of interest with the content of this manuscript.

## References

1. Alobaidy MA, Alraddadi AS, Soames RW (2015) Evaluation of acromial geometry in relation to the cuff tears on Thiel-embalmed cadavers using 3D microscribe digitizer. *Revista Argentina de Anatomía Clínica* 7(2):93–99
2. Aoki M, Ishii S, Usui M (1986) The slope of the acromion and rotator cuff impingement. *Orthop Trans* 10:228
3. Aydin A, Yildiz A, Kalali F, Yildirim OS, Topal M, Dostbil A (2011) The role of acromion morphology in chronic subacromial impingement syndrome. *Acta Orthop Belg* 77(6):733–736
4. Balke M, Schmidt C, Dedy N, Banerjee M, Bouillon B, Liem D (2013) Correlation of acromial morphology with impingement syndrome and rotator cuff tears. *Acta Orthop* 84(2):178–183. <https://doi.org/10.3109/17453674.2013.773413>
5. Banas MP, Miller RJ, Totterman S (1995) Relationship between the lateral acromion angle and rotator cuff disease. *J Shoulder Elb Surg* 4(6):454–461. [https://doi.org/10.1016/S1058-2746\(05\)80038-2](https://doi.org/10.1016/S1058-2746(05)80038-2)
6. Bigliani LU, Morrison DS, April EW (1986) The morphology of the acromion and its relationship to rotator cuff tears. *Orthop Trans* 10:228
7. Chun JM, Yoo HW (1994) Incidence of acromial spur. *J Shoulder Elb Surg* 3:20
8. Cho BP, Kang HS (1998) Articular facets of the coracoclavicular joint in Koreans. *Acta Anat* 163(1):56–62. <https://doi.org/10.1159/000046446>
9. Edelson JG, Luchs J (1995) Aspects of coracoacromial ligament anatomy of interest to the arthroscopic surgeon. *Arthrosc J Arthroscop Relat Surg* 11(6):715–719. [https://doi.org/10.1016/0749-8063\(95\)90115-9](https://doi.org/10.1016/0749-8063(95)90115-9)
10. Edelson JG, Taitz C (1992) Anatomy of the coracoacromial arch: relation to degeneration of the acromion. *J Bone Jt Surg (Br)* 74:589–594
11. Edelson JG (1995) The “Hooked” acromion revisited. *J Bone Jt Surg (Br)* 77:284–287
12. Epstein RE, Schweitzer ME, Frieman BG, Fenlin JM Jr, Mitchell DG (1993) Hooked acromion: prevalence on MR images of painful shoulders. *Radiology* 187(2):479–481. <https://doi.org/10.1148/radiology.187.2.8475294>
13. Farley TE, Neumann CH, Steinbach LS, Petersen SA (1994) The coracoacromial arch: MR evaluation and correlation with rotator cuff pathology. *Skelet Radiol* 23(8):641–645. <https://doi.org/10.1007/BF02580386>
14. Flatow EL, Soslowsky LJ, Ticker JB, Pawluk RJ, Hepler M, Ark J, Mow VC, Bigliani LU (1994) Excursion of the rotator cuff under the acromion patterns of subacromial contact. *Am J Sports Med* 22(6):779–788

15. Getz JD, Recht MP, Piraino DW, Schils JP, Latimer BM, Jellema LM, Obuchowski NA (1996) Acromial morphology: relation to sex, age, symmetry, and subacromial enthesophytes. *Radiology* 199:737–742. <https://doi.org/10.1148/radiology.199.3.8637998>
16. Hamid N, Omid R, Yamaguchi K, Steger-May K, Stobbs G, Keener JD (2012) Relationship of radiographic acromial characteristics and rotator cuff disease: a prospective investigation of clinical, radiographic, and sonographic findings. *J Shoulder Elb Surg* 21(10):1289–1298. <https://doi.org/10.1016/j.jse.2011.09.028>
17. Hirano M, Ide J, Takagi K (2002) Acromial shapes and extension of rotator cuff tears: magnetic resonance imaging evaluation. *J Shoulder Elb Surg* 11(6):576–578. <https://doi.org/10.1067/mse.2002.127097>
18. MacGillivray JD, Fealy S, Potter HG, O'Brien SJ (1998) Multiplanar analysis of acromion morphology. *Am J Sports Med* 26(6):836–840
19. Mahakkanukrauh P, Surin P (2003) Prevalence of osteophytes associated with the acromion and acromioclavicular joint. *Clin Anat* 16(6):506–510. <https://doi.org/10.1002/ca.10182>
20. Moor BK, Wieser K, Slankamenac K, Gerber C, Bouaicha S (2014) Relationship of individual scapular anatomy and degenerative rotator cuff tears. *J Shoulder Elb Surg* 23(4):536–541. <https://doi.org/10.1016/j.jse.2013.11.008>
21. Musil D, Sadvoský P, Rost M, Stehlík J, Filip L (2012) Relationship of acromial morphology and rotator cuff tears. *Acta chirurgiae orthopaedicae et traumatologiae Cechoslovaca* 79(3):238–242
22. Natsis K, Tsikaras P, Totlis T, Gigis I, Skandalakis P, Appell HJ, Koebke J (2007) Correlation between the four types of acromion and the existence of enthesophytes: a study on 423 dried scapulae and review of the literature. *Clin Anat* 20(3):267–272. <https://doi.org/10.1002/ca.20320>
23. Neer CSII (1972) Anterior acromioplasty for the chronic impingement syndrome in the shoulder: a preliminary report. *J Bone Jt Surg* 54(Am):41–50. <https://doi.org/10.2106/JBJS.8706.cl>
24. Neer CS (1983) Impingement lesion. *Clin Orthop Rel Res* 173:70–77
25. Nicholson GP, Goodman DA, Flatow EL, Bigliani LU (1996) The acromion morphologic condition and age-related changes: a study of 420 scapulae. *J Shoulder Elb Surg* 5:1–11. [https://doi.org/10.1016/S1058-2746\(96\)80024-3](https://doi.org/10.1016/S1058-2746(96)80024-3)
26. Ogata S, Uthoff HK (1990) Acromial enthesopathy and rotator cuff tear: a radiologic and histologic postmortem investigation of the coracoacromial arch. *Clin Orthop Rel Res* 254:39–48. <https://doi.org/10.1097/00003086-199005000-00006>
27. Oh JH, Kim JY, Lee HK, Choi JA (2010) Classification and clinical significance of acromial spur in rotator cuff tear: heel-type spur and rotator cuff tear. *Clin Orthop Rel Res* 468:1542–1550. <https://doi.org/10.1007/s11999-009-1058-5>
28. Panni AS, Milano G, Lucania L, Fabbriani C, Logroscino CA (1996) Histological analysis of the coracoacromial arch: correlation between age-related changes and rotator cuff tears. *J Arthroscop Relat Surg* 12(5):531–540. [https://doi.org/10.1016/S0749-8063\(96\)90190-5](https://doi.org/10.1016/S0749-8063(96)90190-5)
29. Paraskevas G, Tzaveas A, Papaziogas B, Kitsoulis P, Natsis K, Spanidou S (2008) Morphological parameters of the acromion. *Folia Morphol* 67(4):255–260
30. Prescher A (2000) Anatomical basics, variations, and degenerative changes of the shoulder joint and shoulder girdle. *Eur J Radiol* 35(2):88–102. [https://doi.org/10.1016/S0720-048X\(00\)00225-4](https://doi.org/10.1016/S0720-048X(00)00225-4)
31. Sangiampong A, Chompoopong S, Sangvichien S, Thongtong P, Wongjitraporn S (2007) The acromial morphology of Thais in relation to gender and age: study in scapular dried bone. *J Med Assoc Thai* 90(3):502–507
32. Shah NN, Bayliss NC, Malcolm A (2001) Shape of the acromion: congenital or acquired: a macroscopic, radiographic, and microscopic study of acromion. *J Shoulder Elb Surg* 10(4):309–316. <https://doi.org/10.1067/mse.2001.114681>
33. Speer KP, Osbahr DC, Montella BJ, Apple AS, Mair SD (2001) Acromial morphotype in the young asymptomatic athletic shoulder. *J Shoulder Elb Surg* 10(5):434–437. <https://doi.org/10.1067/mse.2001.117124>
34. Toivonen DA, Tuite MJ, Orwin JF (1995) Acromial structure and tears of the rotator cuff. *J Shoulder Elb Surg* 4:376–383. [https://doi.org/10.1016/S1058-2746\(95\)80022-0](https://doi.org/10.1016/S1058-2746(95)80022-0)
35. Tuite MJ, Toivonen DA, Orwin JF, Wright DH (1995) Acromial angle on radiographs of the shoulder: correlation with the impingement syndrome and rotator cuff tears. *AJR Am J Roentgenol* 165(3):609–613. <https://doi.org/10.2214/ajr.165.3.7645479>
36. Vahakari M, Leppilahti J, Hyvonen P, Ristiniemi J, Paivansalo M, Jalovaara P (2010) Acromial shape in asymptomatic subjects: a study of 305 shoulders in different age groups. *Acta Radiol* 51(2):202–206
37. Vassalou E, Fragkiadoulaki V, Maldas P, Magkanas E, Karantanas A, Heraklion GR (2012) Age-related coracoacromial arch morphometry: a MR imaging study. *Skelet Radiol* 40:810
38. Wang J, Huang F (2009) A biomechanical study on coracoacromial ligament as anterosuperior restraint of shoulder joint. *Chin J Reparative Reconstr Surg* 23(1):49–51
39. Worland RL, Lee D, Orozco CG, SozaRex F, Keenan J (2003) Correlation of age, acromial morphology, and rotator cuff tear pathology diagnosed by ultrasound in asymptomatic patients. *J South Orthop Assoc* 12:23–26