Van Med J 33 (4):479 4-486, 2026
DOI: 10.5505/vmj.2026.60490

A Geometric Morphometric Study of Late Byzantine and Modern Period Scapular Glenoid Cavity

Senem Turan Ozdemir [1*], Ilker Ercan [2], Juan Alberto Sanchis Gimeno [3,4], Ibrahim Sahin [5], Zejun Xu [6], Ece Ercan Stanczak[7], Arda Uzunoglu[8]

[1]*Bursa Uludag University, Department of Anatomy, Faculty of Medicine, Bursa, Turkiye*

[2] *Bursa Uludag University, Department of Biostatistics, Faculty of Medicine, Bursa, Turkiye*

[3] *University of Johannesburg, Department of Human Anatomy and Physiology, Faculty of Health Sciences, Johannesburg, South Africa*

[4] *University of Valencia, GIAVAL Research Group, Department of Anatomy and Human Embryology, Faculty of Medicine and Odontology, Valencia, Spain*

[5] *Bursa Uludag University, Department of Biostatistics, Institute of Health Sciences, Bursa, Turkiye*

[6] *Jinzhou Medical University, Institute of Anthropology, Liaoning, China*

[7] *University of Warsaw, Faculty of Archaeology, Warsaw, 00-927 Poland*

[8] *Yalova University, Department of Biostatistics and Medical Informatics, Faculty of Medicine, Yalova, Turkiye*

Abstract

Introduction: This study aimed to apply geometric morphometry to test the hypothesis that there are differences in glenoid cavity shape between late medieval soldiers of the Byzantine Empire (13th century) and present subjects who lived in the same area.

Methods: A total of 54 scapulae were investigated: 21 belonged to Byzantine soldiers excavated in Nicaea (İznik) and 33 to the modern period. Six landmarks were defined on the ventral view of the glenoid cavity. Shape comparisons were performed using Procrustes analysis, and cluster analysis was used to classify the glenoid cavities.

Results: No significant difference was observed in the mean shapes of the right scapular glenoid cavity between the Byzantine and present periods (p=0.723). However, the mean shapes of the left glenoid cavity were found to differ according to period (p=0.003). In cluster analysis, the distribution of periods did not differ for the right side (p=0.689), whereas a marginally significant difference was observed for the left side (p=0.078).

Conclusion: There is no difference in glenoid cavity shape between modern humans and Byzantine soldiers on the right side, but there is a difference on the left side, which may be related to the use of heavy weapons such as shields.

Key words: Glenoid cavity; scapula; military personnel; anatomic landmarks; anthropology.

Introduction

The scapula, which comprises a major part of the pectoral girdle, is a flat triangular bone located in the dorsal part of the thorax. The lateral angle of the scapula is truncated and possesses the cavity known as the glenoid cavity or glenoid fossa. The morphology of the glenoid cavity is highly variable, and no consensus exists regarding how to classify the different forms (1). The scapula plays a role in shoulder function and arm movements both anatomically and biomechanically. The morphological and morphometric features of the glenoid cavity play a vital role in the stability and mobility balance achieved by the glenoid cavity, which provides a bony base for both sagittal and vertical stability of the glenohumeral joint. It is the main component of the locomotor system as it connects the upper limb and trunk and is involved in various ways during different movement behaviors (e.g., grasping, climbing, and brachiation, among others). Many researchers have associated variations in scapular form with genetic, musculoskeletal, behavioral, locomotor and/or ecological variables/factors (2-9). Scapular morphology is thought to be influenced by a combination of historical, developmental and functional morphological factors (2-7). Although it is evaluated that there is a strong genetic control on the general shape of the glenoid cavity, the effect of biomechanical factors besides phylogenetic factors is emphasized (5, 7). The

*Corresponding Author: Senem Turan Ozdemir Department of Anatomy, Faculty of Medicine, Bursa Uludag University, Bursa, Turkiye
E-mail: senem@uludag.edu.tr **Orcid:** Senem Turan Ozdemir 0000-0002-0407-3608, Ilker Ercan 0000-0002-2382-290X, Juan Alberto Sanchis Gimeno 0000-0002-2599-8474, Ibrahim Sahin 0000-0001-9031-3040, Zejun Xu 0009-0001-8696-6062, Ece ErcanStanczak 0009-0004-2870-2001, Arda Uzunoglu 0000-0002-7224-8588

Received: 13.05.2026, Accepted: 24.09.2026

Content of this journal is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

morphology of the scapular glenoid cavity has long been of interest to scholars of human evolution. The effects of lifestyle, sex, adaptation to habitual behavior and locomotor adaptations on glenoid fossa morphology have been investigated between different species and periods. Furthermore, these studies were carried out not only to investigate the historical and evolutionary development of the glenoid fossa, but also to reveal the functional differences in glenoid size between different populations in procedures such as shoulder arthroplasty applications (10). Shape analysis studies have been carried out for a long time by using different bones in order to interpret the variations in different life periods (11, 12). Statistical shape analysis is widely used in medicine, life science and other areas investigating the effects of diseases and environmental factors on the structure of the organ or organism(13). The glenoid cavity is represented in a form that can be analyzed using morphometrics by digitizing a number of landmarks over the surface of the object. These landmarks each represent the same equivalent point from the surface of the glenoid. In sum, geometric morphometry can be used to quantify the variation in shape of the glenoid fossa between remains from the modern and Byzantine periods. As a result, in the present research, we aimed to apply geometric morphometry to the analysis of the scapular glenoid cavity shape of two different samples in people that lived in the same area in different historical periods: the first objective was to analyze the shape of the glenoid cavity in late Byzantine soldiers and the second objective was to analyze the shape differences of the glenoid cavity between Byzantine soldiers and modern subjects. In this context, and regarding historical scapular remains, the Department of Anatomy at Bursa Uludag University Faculty of Medicine, Türkiye, stored a sample of scapulae from skeletons of soldiers dating back to the late Byzantine period (13th century) (12). Moreover, the same Department of Anatomy also stored a sample of scapulae from modern (20th-21st centuries) skeletons. In fact, it is reasonable to assume that modern subjects differ from late Byzantine soldiers in shoulder function and biomechanically, thus resulting in possible scapular shape differences between both samples. As we have access to both late Byzantine and modern samples, it is possible to carry out a geometric morphometric study in order to test the hypothesis that there are differences in glenoid cavity shape between late medieval soldiers of the Byzantine Empire (13th century) and present (20th-21st centuries) subjects.

Materials and Methods

Samples: In order to examine the differences in glenoid cavity shape, 54 (100%) scapulae in the skeletal collections from the late Byzantine and modern human periods were investigated. The material was stored in the osteological collection of the Department of Anatomy at Bursa Uludag University Faculty of Medicine, Türkiye. A total of 21 (38.9%) scapulae, including 12 left and 9 right scapulae examined in the present study date back to the late Byzantine period (13th century), and are part of the collection of bones excavated from a Roman amphitheater in Nicaea, Anatolia, between 1981 and 1985. Nicaea (present-day Iznik) is a small town in northwestern Turkey, on the eastern shore of Lake Iznik. It is the modern successor of the important Byzantine city where the first Christian Council was held in 325. All excavations and bone collections, as well as their assessment, were performed by archaeologists and anthropologists (12). All skeletons were from males with an average age of 35 years (ranging between 25 and 50 years) and belonged to soldiers of the Byzantine Empire (12, 14). In addition, 33 (61.1%) modern period scapulae (14 left, 19 right) stored Bursa Uludag University were also included in the analysis for comparative purposes. Modern period scapulae belonging to the 21st century is used in student practices and were obtained from the cemeteries of Bursa city near Iznik in Anatolia, where unfortunately there is no gender and age information. The study is based on the comparison of the scapular glenoids belonging to soldiers of the Byzantine Period and scapular glenoids belonging to the modern period, from people who lived in the same geographical area.

Collection of two-dimensional landmarks: Landmarks were marked with TpsDig version 2.30 software. For each image, 6 landmarks on the ventral view of the glenoid cavity were defined (Figure 1). First, the top (1st landmark) and bottom (2nd landmark) of the glenoid cavity of the scapula were marked. Then, the distance between the first and second landmarks was divided into three equal parts. The other landmarks were marked by drawing lines from the equal distances with 90-degree angles. Figure 1

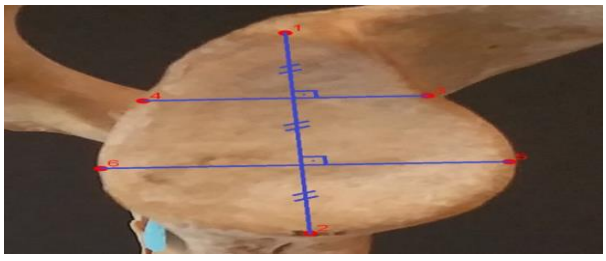


Figure 1: Landmarks on a glenoid cavity

shows the landmarks on a glenoid cavity. When identifying landmarks to highlight shape differences, repeatability in marking and the provision of sufficient information about the shape are the most important factors. For the glenoid shape, in our study we used 6 reliable landmarks to obtain shape information.

Ethical approval: Ethical committee approval is not required for studies involving bones

Statistical shape analysis: Shape comparisons were performed using Procrustes analysis. Box's M test was used to determine if the variance-covariance matrices were homogeneous. When the matrix of variance-covariance was homogenous, the Hotelling T^2 test was used to compare Procrustes mean shapes, otherwise James's F_j test was used for statistical comparison of shape differences. To obtain an overall assessment of shape variability, the root mean square of Kendall's Riemannian distance rho to the mean shape was employed. Cluster analysis was used to classify glenoid cavities of scapulae. The Procrustes distance was used to calculate dissimilarity between individuals. The complete linkage method was used to merge the clusters. Fisher's exact test was performed to compare categorical variables between groups. Categorical variables were expressed as n (%). Statistical analysis was performed with the "shapes" package of R-3.6.3, SPSS-22.0, tpsSmall and Clustan Graphics v.8.0. Results were considered statistically significant at $\alpha = 0.05$. Since the sample size is small and it is not possible to increase the Byzantine sample size, if the p-value is found between 0.05 - 0.10, it is reported as marginally significant.

Landmark reliability: According to the generalizability theorem (GT), we measured the intrarater reliability coefficient (G) for a two-facet crossed design (landmark pairs-by-rater-by-subject) (15). The generalizability coefficient is used in the GT to describe the reliability of relative (norm-referenced) interpretations (16). The landmarks were marked by a single rater. Using repeated landmarks on groups and sides, the rater's reliability was evaluated. A single investigator collected the landmarks on the glenoid cavity, and after a month, the same investigator re-marked the same landmarks on all Byzantines and present subjects. This analysis shows that left-Byzantines (G=0.9977), right-Byzantines (G=0.9962), left-present (G=0.9973), and right-present (G=0.9987) subjects have good repeatabilities. Landmark reliabilities were calculated from the link (15). (http://biostat.home.uludag.edu.tr/landmark_reliability/G_coefficient.html)

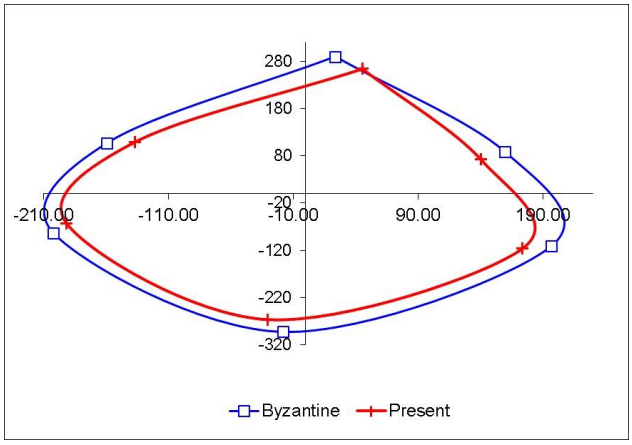


Figure 2: Procrustes mean shapes from Byzantine period (□) and present period (+) for right scapulae

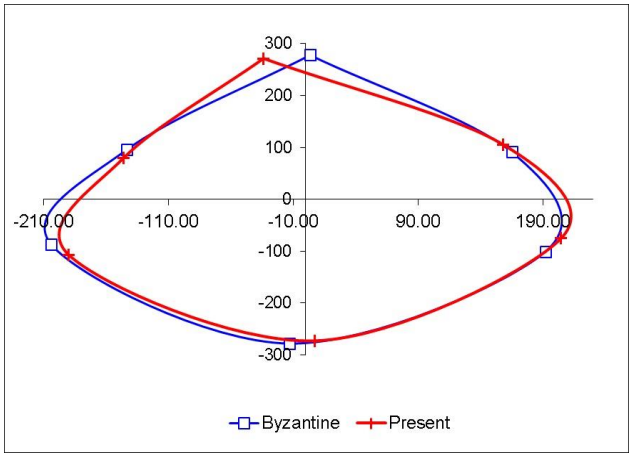


Figure 3: Procrustes mean shapes from Byzantine period (□) and present period (+) for left scapulae

Results

No significant difference was observed in the mean shapes of the right scapular glenoid cavity between the Byzantine and present periods (p=0.723) (Figure 2). However, the mean shapes of the left side scapular glenoid cavity were found to differ according to the Byzantine and present periods (p=0.003) (Figure 3). The shape variability for left scapulae was 0.044 in the Byzantine period and 0.051 in the present period. The shape variability for right scapulae was 0.057 in the Byzantine period and 0.047 in the present period. Shape variabilities for both sides in each period were similar. When the scapula bones were investigated according to the right side, two notable clusters were identified at the 0.121 dissimilarity level. In cluster-I, 26.7% (4/15) percent of the scapula bones were from the

Byzantine period and 73.3% (11/15) percent of the scapula bones were from the present period. In cluster-II, 38.5% (5/13) percent of the scapula bones were from the Byzantine period and 61.5% (8/13) percent of the scapula bones were from the present period (Figure 4).

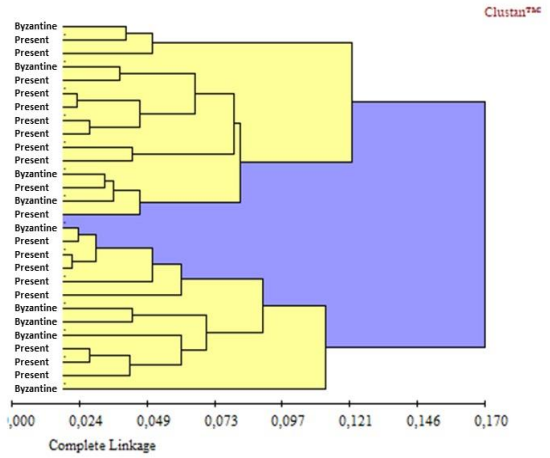


Figure 4: Dendrogram of the classification of right-side scapulae

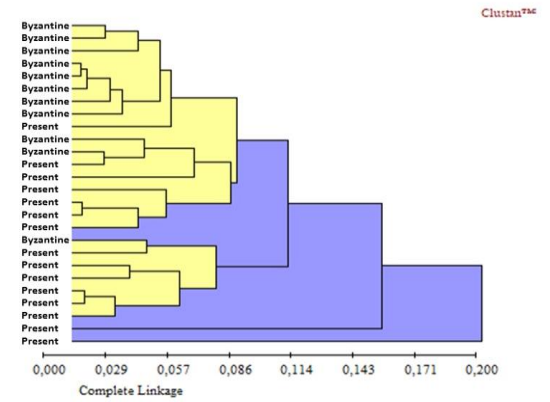


Figure 5: Dendrogram of the classification of left side scapulae

When statistically comparing the two clusters according to percentage distribution of periods, no statistically significant difference was found (p=0.689) (Table 1). When the scapula bones were investigated according to the left side, two notable clusters were identified at the 0.089 dissimilarity level. Two units did not display clustering at this similarity level. In cluster-I, 58.8% (10/17) percent of the scapula bones were from the Byzantine period and 41.2% (7/17) percent of the scapula bones were from the present period. In cluster-II, 14.3% (1/7) percent of the scapula bones were from the Byzantine period and 85.7% (6/7) percent of the scapula bones were from the present period (Figure 5). When statistically comparing the two clusters according to percentage distribution of periods, no statistically significant difference was found (p=0.078) (Table 1).

Table 1: Comparisons of the two clusters for left and right scapulae according to periods

	Right side		Left side	
	Byzantine n (%)	Present n (%)	Byzantine n (%)	Present n (%)
Cluster-I	4(26.7)	11(73.3)	10(58.8)	7(41.2)
Cluster-II	5(38.5)	8(61.5)	1(14.3)	6(85.7)
p	0.689		0.078	

Discussion

In this study, we compared the glenoid cavity shape of people living in the same geographical region during two different periods, specifically between Byzantine soldiers and the modern Anatolian population. Anatolia, thanks to its geographical location, is situated at the crossroads of three major continents and has hosted many civilizations. The Byzantine periods are particularly noteworthy and important in this respect. In our study, the morphometric analysis of glenoid cavity bones from the modern Anatolian population and Byzantine soldiers was examined using two different approaches: comparing and classifying differences in shape. For the glenoid cavity shape on the right, statistical analysis indicated no significant difference in terms of average shape in the morphometric analysis. In terms of glenoid cavity shape examined using clustering analysis, no difference was found between clusters according to periods in the classification analysis. For the glenoid cavity shape on the left, statistical analysis indicated significant difference in terms of average shape in the morphometric analysis. In terms of glenoid cavity shape examined using clustering analysis, a marginally significant difference was observed between clusters according to periods.

Investigation of metric and non-metric properties of human skeletal remains provides important data in terms of both paleopathology and functionality. In addition to the possible habitual movement and lifestyle of individuals, information is also obtained about their postural characteristics. For decades, morphometric assessment of sex and ancestry was dominated by studies of the skull and, rarely, the postcrania, using discriminant

function analyses of linear measurements. Anatomists variously describe the shape of the glenoid cavity in different ways: teardrop or pear-shaped, round, ovoid or an inverted comma-shape (1, 2, 11, 17, 18, 19). This dissimilarity results in a variety of different anthropometric parameters to describe the glenoid cavity. There are many reports on glenoid size using different measurement methods, but the number of studies evaluating shape using the geometric morphometry method is more limited. Studies using the geometric morphometric method have been used both to reveal the evolutionary developmental differences of the glenoid shape and to determine the functional differences (3, 5, 7, 8, 20, 21). Form, function and phylogeny, epigenetics and genetics are important factors for scapular glenoid shape. Macias and Churchill (22) suggested that functional explanations may be appropriate for certain aspects of glenoid fossa morphology; however, they emphasized that factors such as allometry and evolutionary development should be considered rather than functional morphology. Arias-Martorell et al. (6) reported that the shape of the glenoid is not as driven by locomotor constraints as that of the proximal humerus. They concluded that the shape of the glenoid space failed to distinguish existing taxa with respect to locomotor categories (6). Although it has been suggested that primate scapular morphology is primarily a product of function rather than phylogeny, Püschel and Sellers (7) have stated that shape has an important phylogenetic signal. They reported that there is a significant relationship between scapular shape and its biomechanical performance, and that therefore, at least some of the scapular shape variation is due to non-phylogenetic factors and is probably related to functional demands (7). While factors such as race, gender, climate, genetics, environmental and cultural characteristics, and lifestyle have a more dominant effect on bones like the skull and pelvis, it is difficult to definitively say which factor is more dominant, especially in postcranial bones. Depending on lifespan and particularly hand use, it can be assumed that motor functions, lifestyle, habits, hunting and climbing habits, and for certain periods, military service and the use of weapons may have an impact on the postcranial skeleton. The known characteristics of the Byzantine-era bones in our study are that the average age range of the subjects is 35-50 and that all were Byzantine soldiers. These bones were found in the İznik excavations, and all examinations of the bones were carried out by archaeologists and anthropologists. It is known that right v left size differences in the body (i.e. asymmetry) are more pronounced in upper than in lower human limbs of individuals engaged in heavy physical work with lateralized behaviors and biomechanical pressures (9). As noted by Kubicka et al. (19), movements in human upper limbs involve simultaneous motion of the clavicle, scapula, and humerus, and glenoid shape differences may be caused by adaptive structural changes (23), as asymmetry in shape of the glenoid cavity may be caused by different types and levels of physical activities (9, 23).This happened in the Byzantine soldiers because their physical activity may have been very different in comparison to the modern population and can be the reason for the different shape results obtained between them and the modern sample. In terms of left-sided scapula bones, there was marginal significance for left-sided bones in the distribution of individuals in clusters formed for bone shapes. When comparing the Byzantine and modern period glenoid cavities in terms of shape variation, a difference was detected only for the left side glenoid cavity, while no difference was detected for the right side. Although this does not appear to be a significant determinant of locomotor habit, it may be related to scapula shape between different periods, the differences in shape detected between two different populations living in the same region, or mechanical abilities and limitations of the scapula. In this context, the Byzantine sample comprised 13th century soldiers, who were very different in terms of physical activity to the modern Turkish population. All the above-mentioned data about the Byzantine soldiers may be of paramount interest in the interpretation of the results of the present research, because most muscles responsible for combined motions in the upper limb act on the glenoid cavity, which is exposed to biomechanical loading (9), and may be one of the reasons for the shape differences we detected. In comparison, the modern sample may be considered as a sedentary sample and the Byzantine sample as an athletic sample. Moreover, it is known that the scapulae of the soldiers were submitted to stress that would lead to pathologies and injuries (24-27), with the knowledge that fractures of the glenoid fossa are one of the most severe injuries to the scapula (28). This is why we believe that the continuous higher stress to the glenoid cavity of the Byzantine soldiers may be another reason for the results we obtained. We cannot comment on the dominant side or hand use in the scapulae we studied, which are known to belong to Byzantine-era soldiers. However, considering that the bones we examined

belong to a soldier population, and given that it is historically known that soldiers carried heavy materials such as shields, especially with their left side, this situation represents a certain degree of load bearing on the left side compared to the right, and could form the basis for our findings, particularly regarding the left glenoid fossa. In our study, comparing a group of only men from the Byzantine period with a modern group whose gender and age distribution is unknown may call into question the reliability of the results obtained. However, we anticipate that the lifestyle of a military population would have been significantly different from that of the modern period. Considering the training they received in combat techniques and the duration of weapon use, we believe that the effect of the weapon on the limb used, especially due to the prolonged use of heavy weapons, is undeniable. The difference in shape observed on the left side in our study may be related to the use of heavy weapons such as shields. We do not have demographic information regarding the bones from the modern period. However, we know that the human bones from this period do not belong to soldiers, and we can assume that their lifestyles were certainly more sedentary compared to soldiers. Age and gender are important variables for bone morphology. Sexual dimorphism is known to be more pronounced, especially in bones such as the skull and pelvis. The importance of sexual dimorphism for postcranial bones certainly cannot be ignored. Based on general anatomical observations of modern bones, it can be said that these belong to adults. However, it is of course not possible to determine their gender observationally. This is one of the weaknesses of our study.

Limitations of the study: A significant limitation of the study is the unfortunately limited number of bone samples examined. Another important limitation is the lack of demographic data for the control group. While the Byzantine-era skeletons consist only of male soldiers aged 25-50 years (average 35 years), age and gender information is not available for modern-era samples in this study.

Conclusions

Most of the studies aiming to shed light on evolutionary development and locomotor adaptation have focused on glenoid cavity shape differences between hominids or Neanderthals and modern humans or between different animal species. Considering that the glenohumeral joint is the most mobile region of the body, it is understandable to investigate how the shape of the scapula and glenoid cavity is affected by evolutionary development and locomotor adaptation. In this study, we wondered whether there were differences in the shape of the left and right side of the glenoid cavity between groups of people living in the same region but at two different time periods and with a different lifestyle. In terms of the glenoid cavity, there is no difference between modern humans and Byzantine soldiers on the right side, but there is a difference on the left side. An important limitation of the study is the limited number of bone materials studied.

Use of AI tools: No Artificial Intelligence (AI) tools were used in the preparation of this manuscript.

Conflict of interest: The authors declare no conflict of interest.

Funding: No financial support was received for this study.

Data availability statement: The datasets generated and/or analysed during the current study are available from the corresponding author upon reasonable request.

Authors Contrubutions: Concept: I.E., S.T.O.; Data Collection or Processing: S.T.O., Z.X; Analysis or Interpretation: I.E., I.S., Z.X; Literature Search: S.T.O., J.A.S.G.; Writing: All authors; Critical Review: All authors

References

1. De Wilde LF, Berghs BM, Audenaert E, Sys G, Van Maele GO, Barbaix E. About the variability of the shape of the glenoid cavity. Surg Radiol Anat. 2004;26(1):54-59. doi:10.1007/s00276-003-0167-1
2. García-Martínez D, Green DJ, Bermúdez de Castro JM. Evolutionary development of the Homo antecessor scapulae (Gran Dolina site, Atapuerca) suggests a modern-like development for Lower Pleistocene Homo. Sci Rep. 2021;11(1):4102. doi:10.1038/s41598-021-83039-w
3. Young NM. A comparison of the ontogeny of shape variation in the anthropoid scapula: Functional and phylogenetic signal. Am J Phys Anthropol. 2008;136:247-264. doi:10.1002/ajpa.20799
4. Morgan CC. Geometric morphometrics of the scapula of South American caviomorph rodents (Rodentia: Hystricognathi): Form, function and phylogeny. Mamm Biol. 2009;74(6):497-506. doi:10.1016/j.mambio.2008.09.006
5. Di Vincenzo F, Churchill SE, Manzi G. The Vindija Neanderthal scapular glenoid fossa: Comparative shape analysis suggests evo-

devo changes among Neanderthals. J Hum Evol. 2012;62(2):274-285. doi:10.1016/j.jhevol.2011.11.010
6. Arias-Martorell J, Potau JM, Bello-Hellegouarch G, Pérez-Pérez A. Like father, like son: Assessment of the morphological affinities of A.L. 288-1 (A. afarensis), Sts 7 (A. africanus) and Omo 119-73-2718 (Australopithecus sp.) through a three-dimensional shape analysis of the shoulder joint. PLoS One. 2015;10(2):e0117408. doi:10.1371/journal.pone.0117408
7. Püschel TA, Sellers WI. Standing on the shoulders of apes: Analyzing the form and function of the hominoid scapula using geometric morphometrics and finite element analysis. Am J Phys Anthropol. 2016;159:325-341. doi:10.1002/ajpa.22882
8. Green DJ, Spiewak TA, Seitelman B, Gunz P. Scapular shape of extant hominoids and the African ape/modern human last common ancestor. J Hum Evol. 2016;94:1-12. doi:10.1016/j.jhevol.2016.01.001
9. Kubicka AM, Lubiatowski P, Długosz JD, Romanowski L, Piontek J. Directional asymmetry of upper limbs in a medieval population from Poland: A combination of linear and geometric morphometrics. Am J Hum Biol. 2016;28:817-824. doi:10.1002/ajhb.22873
10. Sharma GB, McMahon PJ, Robertson DD. Structure modeling of the glenoid: Relevance to shoulder arthroplasty. J Orthop Res. 2014;32:1471-1478. doi:10.1002/jor.22696
11. Tiwari V, Tiwari S, Das SS, Vasudeva N. Geometric morphometry of glenoid cavity in dry adult scapula and its surgical implications. Int J Sci Res. 2018;7:211-214.
12. Ozdemir ST, Ercan I, Ozkaya G, Cankur NS, Erdal YS. Geometric morphometric study and cluster analysis of late Byzantine and modern human crania. Coll Antropol. 2010;34(2):493-499.
13. Ercan I, Ocakoglu G, Sigirli D, Ozkaya G. Statistical shape analysis and usage in medical sciences: Review. Turkiye Klinikleri J Biostat. 2012;4(1):27-35.
14. Ozbek M. Byzantine skeletons excavated from the Roman open theater (Iznik). Hacettepe Univ J Fac Lett. 1984;2(1):81-89.
15. Ercan I, Ocakoglu G, Guney I, Yazici B. Adaptation of generalizability theory for inter-rater reliability for landmark localization. Int J Tomogr Stat. 2008;9:51-58.
16. Dimitrov DM. Reliability. In: Erford BT, editor. Assessment for counselors. 2nd ed. Boston (MA): Houghton Mifflin; 2006. p. 99-122.
17. Khan R, Satyapal KS, Lazarus L, Naidoo N. An anthropometric evaluation of the scapula, with emphasis on the coracoid process and glenoid fossa in a South African population. Heliyon. 2020;6(1):e03107. doi:10.1016/j.heliyon.2019.e03107
18. Mamatha T, Pai SR, Murlimanju BV, Kalthur SG, Pai MM, Kumar B. Morphometry of glenoid cavity. Online J Health Allied Scs. 2011;10(3):7.
19. Gupta S, Magotra R, Kour M. Morphometric analysis of glenoid fossa of scapula. J Evol Med Dent Sci. 2015;4(45):7761-7766.
20. Plessers K, Vanden Berghe P, Van Dijck C, Wirix-Speetjens R, Debeer P, Jonkers I, et al. Virtual reconstruction of glenoid bone defects using a statistical shape model. J Shoulder Elbow Surg. 2018;27(1):160-166.
21. Bonnevialle N, Geais L, Müller JH, Berhouet J. Effect of RSA glenoid baseplate central fixation on micromotion and bone stress. JSES Int. 2020;4(4):979-986. doi:10.1016/j.jseint.2020.07.004
22. Macias ME, Churchill SE. Functional morphology of the Neandertal scapular glenoid fossa. Anat Rec (Hoboken). 2015;298(1):168-179. doi:10.1002/ar.23072
23. Borsa PA, Laudner KG, Sauers EL. Mobility and stability adaptations in the shoulder of the overhead athlete: A theoretical and evidence-based perspective. Sports Med. 2008;38(1):17-36. doi:10.2165/00007256-200838010-00003
24. McCown M, Grzeszak B. Scapula fracture secondary to static line injury in a 22 year-old active duty soldier. J Spec Oper Med. 2010;10(4):45-47. doi:10.55460/5R60-DGMA
25. Patzkowski JC, Owens BD, Burns TC. Snapping scapula syndrome in the military. Clin Sports Med. 2014;33(4):757-766. doi:10.1016/j.csm.2014.06.003
26. Bartoníček J, Kozánek M, Jupiter JB. Early history of scapular fractures. Int Orthop. 2016;40(1):213-222. doi:10.1007/s00264-015-2821-8
27. Kardouni JR, McKinnon CJ, Seitz AL. Incidence of shoulder dislocations and the rate of recurrent instability in soldiers. Med

Sci Sports Exerc. 2016;48(11):2150-2156. doi:10.1249/MSS.0000000000001011
28. Roberts DC, Power DM, Stapley SA. A review of 10 years of scapula injuries sustained by UK military personnel on operations. J R Army Med Corps. 2018;164(1):30-34.