Guilherme dos Reis Borges Coelho da Fonseca

Associations between Acromial Degenerative Changes, Sex, Age, Side, and Morphology

Dissertação de Mestrado em Evolução e Biologia Humanas, orientada por Doutora Eugénia Cunha e Doutora Maria Susana Garcia, e apresentada ao Departamento de Ciências da Vida da Faculdade de Ciências e Tecnologias da Universidade de Coimbra

Agosto de 2017

• U C •

Universidade de Coimbra

· U C ·

UNIVERSIDADE DE COIMBRA

Universidade de Coimbra

Faculdade de Ciências e Tecnologias

Departamento de Ciências da Vida

Associations between Acromial Degenerative Changes, Sex, Age, Side, and Morphology

Guilherme dos Reis Borges Coelho da Fonseca

(número 2015220931)

Orientação Científica: Professora Doutora Eugénia Cunha (Universidade de Coimbra) e Professora Doutora Maria Susana Garcia (Universidade de Lisboa)

Mestrado em Evolução e Biologia Humanas

CONTENT

Resumo

INTRODUÇÃO: Em contextos clínicos, é assumido que acrómios com morfologia em gancho contribuem para o surgimento de fenómenos de constrição subacromial e roturas tendinosas dos músculos da coifa dos rotadores. Contudo, não se sabe se o formato acromial em gancho é uma característica congénita ou se é consequente à entesopatia ossificante do ligamento coracoacromial. Similarmente, não se conhece a essência das relações que estes entesófitos acromiais têm com outras alterações degenerativas nas articulações glenoumeral e acromioclavicular, apesar de haverem interdependências anatómicas entre estas estruturas do ombro.

OBJETIVOS: Determinar a natureza das relações entre entesófitos coracoacromiais, degeneração glenoumeral e acromioclavicular, sexo, idade, lateralidade e morfologia acromial.

MATERIAIS E MÉTODOS: Foram estudadas um total de 160 escápulas de 80 indivíduos identificados da coleção antropológica Luís Lopes. Especificamente, foi analisada a presença de entesófitos coracoacromiais e de sinais de degeneração glenoumeral e acromioclavicular. Além disso, foi realizada uma análise morfométrica de oito parâmetros morfológicos nas escápulas direitas da amostra, tendo sido utilizadas fotografias ortogonais dos planos lateral e posterior para o efeito. Estatisticamente, foram utilizados *Yule's Q tests* (*Q*) e *Point Biserial Correlation tests* (r_{pb}) para definir a direção e força de associações relevantes.

RESULTADOS E DISCUSSÃO: Foram encontradas associações positivas entre idade (>55 anos) e a presença de entesófitos coracoacromiais (Q= 0.67; p< 0.05), degeneração glenoumeral (Q= 0.97; p< 0.05) e acromioclavicular (Q= 0.96; p< 0.05). Também foram descobertas associações entre a presença de entesófitos com espaços subacromiais (r_{pb}= -0.22; p< 0.05) e glenoumerais (r_{pb}= -0.44; p< 0.05) diminuídos e com distâncias acromiais postero-anteriores aumentadas (r_{pb}= 0.23; p< 0.05). Os acrómios com entesófitos exibiam frequentemente, nas suas superfícies caudais, sinais de remodelação óssea com formato de pequenas "facetas" ovoides. Globalmente, conceitos nas áreas da biologia óssea, da evolução e biomecânica do ombro auxiliam a compreensão das associações verificadas neste estudo.

PALAVRAS-CHAVE: esporão acromial; entesófito coracoacromial; degeneração glenoumeral; degeneração acromioclavicular; morfometria escapular.

This page intentionally left blank.

Abstract

INTRODUCTION: In clinical contexts, it is assumed hooked acromia contribute to subacromial impingement and rotator cuff tears. However, it remains unclear whether acromial morphology is influenced by the presence of coracoacromial enthesophytes. Similarly, little is known about the relationship of enthesophytes with other degenerative signs at the glenohumeral and acromioclavicular joints, despite the existing anatomical interdependencies between these shoulder structures.

OBJECTIVES: To explore associations between coracoacromial enthesophytes, glenohumeral degeneration, acromioclavicular degeneration, sex, age, side, and acromial morphology.

MATERIALS AND METHODS: A total 160 scapulae of 80 identified subjects in the Luís Lopes anthropological collection were inspected for signs of coracoacromial enthesopathy, glenohumeral, and acromioclavicular degeneration. Additionally, the posterior and lateral orthogonal planes of all right scapulae were photographed and morphometrically assessed on eight morphological parameters. Statistically, Yule's Q tests (*Q*) and Point Biserial Correlation tests (r_{pb}) were used to assess the strength and direction of relevant associations.

RESULTS AND DISCUSSION: Positive associations existed between age (>55 years) and coracoacromial enthesophytes (Q= 0.67; p< 0.05), glenohumeral (Q= 0.97; p< 0.05) and acromioclavicular degeneration (Q= 0.96; p< 0.05). Also, enthesophytes were associated with diminished subacromial (r_{pb}= -0.22; p< 0.05) and glenohumeral spaces (r_{pb}= -0.44; p< 0.05) and with increased acromial postero-anterior lengths (r_{pb}= 0.23; p< 0.05). Moreover, acromia with enthesophytes often exhibited inferiorly protruding, non-native, oval "facets" of remodelled bone. Overall, concepts regarding bone biology, shoulder evolution and biomechanics help explain these clinically relevant associations.

KEY-WORDS: acromial spur; coracoacromial enthesophyte; glenohumeral degeneration; acromioclavicular degeneration; scapula morphometrics.

This page intentionally left blank.

1 INTRODUCTION

1.1 Embryology and Anatomy of Acromion and Related Structures

The acromion is a very noticeable and clinically relevant anatomical feature of the human scapula (***Figure 1.1***).

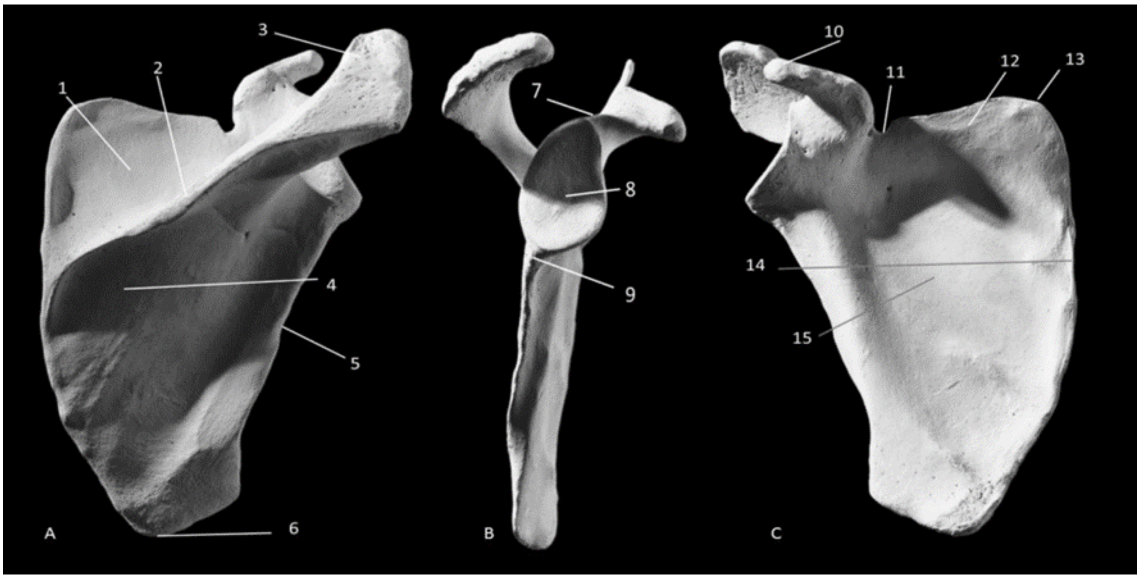

Figure 1.1 View of right scapula in the (A) posterior aspect; (B) lateral aspect; and (C) anterior aspect: 1 – supraspinous fossa; 2 – spine of scapula; 3 – acromion; 4 – infraspinous fossa; 5 – lateral border; 6 – inferior angle; 7 – supraglenoid tubercle; 8 – glenoid cavity; 9 – infraglenoid tubercle; 10 – coracoid process; 11 – suprascapular notch; 12 – superior border; 13 – superior angle; 14 – medial border; 15 – subscapular fossa [illustration adapted from White and colleagues (2011, pp. 166–168)].

Embryologically, the acromion derives from the development of up to four secondary ossification centres (***Figure 1.2***): pre-acromion (the anterior centre), meso-acromion (the middle centre), meta-acromion (the posterior centre) and basi-acromion (located at the base of the scapular spine). Usually, these ossification centres start to appear at as early as 14 years of age and become completely fused by the age of 25 years. However, *os acromiale* results from a permanent failure of consolidation between the ossification centres of the acromion (Fujii, Takeda, & Miyatake, 2015; Yammine, 2014).

Anatomically, the acromion is the lateral extension of the spine of the scapula that projects anteriorly to lie above the glenoid cavity. Generally, its cranial surface is rough, whereas its caudal surface is comparatively smooth, when bony changes are not present (McMinn, 1990, pp. 72–78; Standring et al., 2008, pp. 793–814; Tubbs, Shoja, & Loukas, 2016, pp. 45–48).

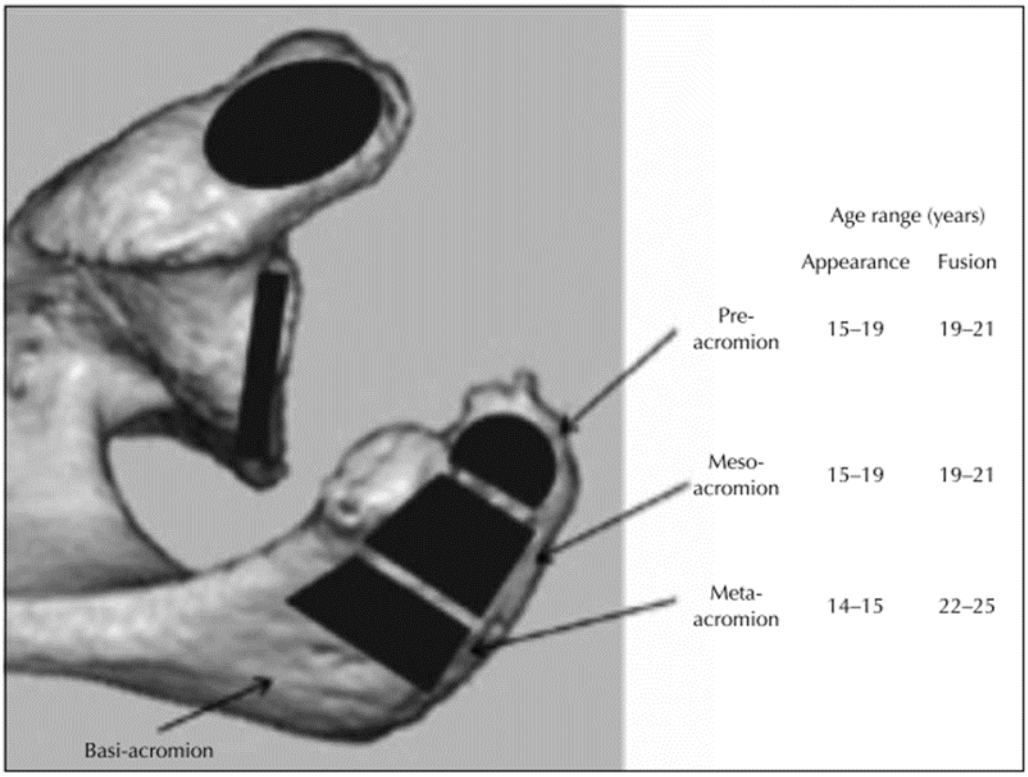

Figure 1.2 Superior aspect of coracoid process, glenoid cavity, and acromion in a right scapula. The location of the secondary ossification centres of these structures are presented. Similarly, the age of appearance and fusion of the secondary ossification centres of the acromion are displayed [illustration adapted from Fujii and colleagues (2015, p. 230)].

The lateral border of the acromion is thick and irregular and gives origin to the middle fibres of the deltoid muscle, sometimes via acromial ridges or tubercles. Its medial border is short and is marked by the presence of a small and oval facet, for articulation with the lateral end of the clavicle. Despite its small size, the acromioclavicular joint plays a key role in enabling a wide range of motion in the shoulder. The fibrous capsule of the acromioclavicular joint attaches around the margins of this clavicular facet. Behind the facet, the medial surface of the acromion anchors the horizontal fibres of the trapezius muscle (McMinn, 1990, pp. 72–78; Standring et al., 2008, pp. 793–814; Tubbs et al., 2016, pp. 45–48).

Parallelly, the medial and lateral acromial borders converge anteriorly to form the tip of the acromion. It is mainly from this point that the apex of the strong coracoacromial ligament attaches and then spans to its broader base at the dorsolateral aspect of the coracoid process, usually forming a triangular or "V" shaped ligament (***Figure 1.3***). Together, the coracoacromial ligament, the acromion, and the coracoid process form a protective coracoacromial arch above the glenohumeral joint (McMinn, 1990, pp. 72–78; Standring et al., 2008, pp. 793–814; Tubbs et al., 2016, pp. 45–48).

The glenohumeral joint is the most mobile in the body, yet also very unstable, as the rounded head of the humerus is considerably larger than the shallow glenoid cavity. The presence of the coracoacromial arch is one of the few anatomical aspects of the shoulder that provides glenohumeral stability, by preventing superior displacement of the humeral head in shoulder movements (McMinn, 1990, pp. 72–78; Standring et al., 2008, pp. 793–814; Tubbs et al., 2016, pp. 45–48).

Additionally, the action of the tendons of the rotator cuff muscles (supraspinatus, infraspinatus, teres minor, subscapularis) that surround the joint also provide additional glenohumeral support (Lugo, Kung, & Ma, 2008; McMinn, 1990, pp. 72–78; Standring et al., 2008, pp. 793–814; Tubbs et al., 2016, pp. 45–48).

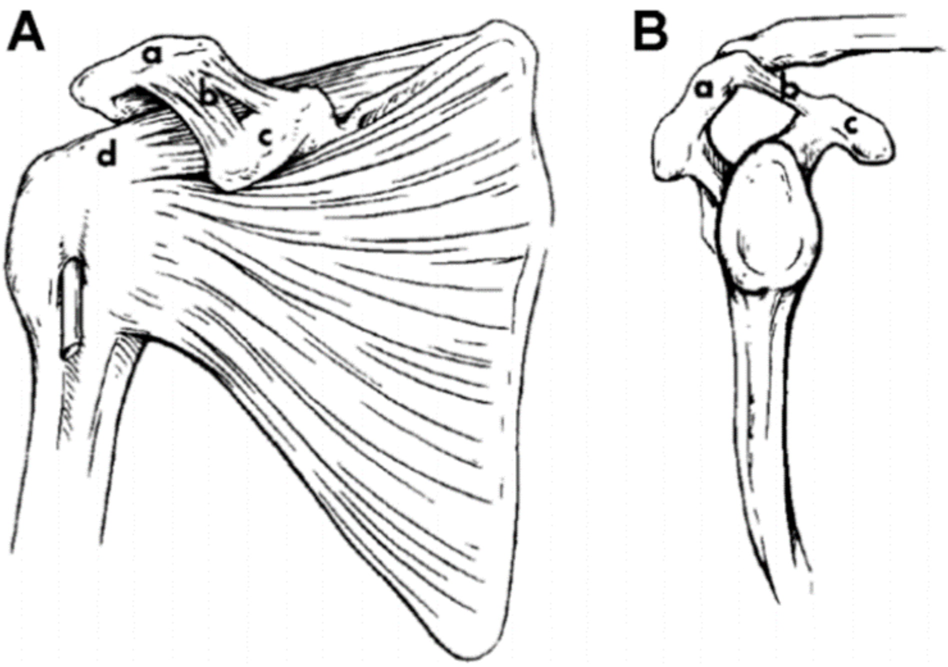

Figure 1.3 Anterior view of right shoulder joint (A) and lateral view of scapula and coracoacromial arch (B): a – acromion; b – coracoacromial ligament; c – coracoid process; d – tendon of supraspinatus muscle [illustration adapted from Soslowsky and colleagues (1994)].

1.2 Clinical Significance of Coracoacromial Morphology

Clinically, it has long been believed that the overall shape, size, and relative scapular position of the acromion and coracoacromial arch are associated to shoulder impairments (Bigliani, Morrison, & April, 1986; Bigliani, Ticker, Flatow, Soslowsky, & Mow, 1991; Neer, 1972, 1983). For instance, it has become commonly acknowledged that the physical impingement of subacromial structures, such as of the subacromial bursa and tendons of the rotator cuff muscles

(***Figure 1.3***), between a highly curved or "hook-like" acromion and the humeral head may lead to injury (Neer, 1972, 1983).

Several authors have claimed that hooked acromial shape can be an inherent anatomical variant of individuals (Bigliani et al., 1986; Nicholson, Goodman, Flatow, & Bigliani, 1996; Vähäkari et al., 2010). On the other hand, other researchers have stated the hooking could be exacerbated by acquired degenerative changes (Edelson, 1995; Edelson & Taitz, 1992). Particularly, the presence of acromial enthesophytes protruding from the antero-inferior edge of the acromion may also contribute to a non-innate hooked shape of acromia (Edelson, 1995; Nicholson et al., 1996).

1.3 Coracoacromial Enthesophytes and other Degenerative Changes

Acromial enthesophytes result from calcifications within the substance of the coracoacromial ligament, and have been attributed to traction forces transmitted through the ligament. Concomitantly, biomechanical data have shown the ligament to be a dynamic transmitting brace between the coracoid process and acromion. Moreover, the favoured location of enthesophytes at the antero-inferior margin of the acromia may confirm that the ligament is a major load-bearing and load-responsive structure. Indeed, and as previously stated, the insertion of the ligament at the acromion is narrower, thus suggesting increased strain, whereas the insertion of the ligament at the coracoid process is broader (Fealy, April, Khazzam, Armengol-Barallat, & Bigliani, 2005; Rothenberg, Gasbarro, Chlebeck, & Lin, 2017).

Historically, it is likely that coracoacromial enthesophytes have been described and studied for nearly a century. However, throughout most of the 20th century, authors used a remarkably inconsistent terminology across the works published on the issue of acromial degenerative changes (Chambler & Emery, 1997). Thus, researchers have encountered and described acromial "spurs" (Bigliani et al., 1986), "osteophytes" (Ozaki, Fujimoto, Nakagawa, Masuhara, & Tamai, 1988), "plaques" (Graves, 1922), "hyperthrophic changes" (Codman, 1934), "beaks" (Ogata & Uhthoff, 1990), "exostoses" (Craig, 1986), "hooks" (Edelson, 1995) or "excrescences" (Neer, 1972).

Fortunately, owing to the anatomical descriptions used, it is currently possible to relate some of these variedly-named osteological lesions to coracoacromial enthesopathy. Nevertheless, it is still unclear whether the presence of enthesophytes is related to other degenerative changes found on the acromioclavicular and glenohumeral joints. Regrettably, less than a handful of studies have briefly tackled this topic (Edelson, 1995; Edelson & Taitz, 1992; Nicholson et al., 1996; Roberts, Peters, & Brown, 2007), even though there are obvious structural, functional, and clinical interdependences between the coracoacromial arch, the acromioclavicular joint, and the glenohumeral joint.

1.4 Objectives of Study

The main objective of this study was to appraise the associations between coracoacromial enthesopathy, acromioclavicular degeneration, and glenohumeral degeneration, as well as each respective association to sex, age, and body side. Likewise, it was intended to clarify the relationship between scapular morphology and the presence of enthesophytes.

This page intentionally left blank.

2 MATERIALS AND METHODS

2.1 Sampling Procedure

For this study, dried human scapulae of the 20th century Luís Lopes anthropological collection (MUHNAC.MB61) of the National Museum of Natural History and Science, Lisbon, were used. Specifically, 160 left and right scapulae belonging to a stratified random sample of 80 identified individuals were analysed.

Subjects were sampled, one by one, from the database of the Luís Lopes collection via a computerized random number generator, with criteria of age and sex being controlled. Therefore, the individuals in the sample were equally stratified into four age groups (≤35; 36 to 55; 56 to 75; >75) of 20 elements each. Similarly, in every age strata, there was a split division in terms of sex (ten male; ten female).

To reach the final sample of 80 individuals, the scapulae of 348 people had to be checked. Consequently, only 23% of the inspected individuals was accepted into the study. From the 268 excluded individuals (***Figure 2.1***), 237 showed an absent or damaged scapula. This large number was not surprising because scapulae are mostly composed by delicate trabecular bone and thin cortical bone that are highly susceptible to taphonomy (Quatrehomme & Işcan, 1997). Furthermore, four individuals were excluded due to the presence of clearly non-degenerative pathological signs, whereas two were excluded due to mismatching information regarding their identity. Finally, 25 individuals were left out due to a non-ossification of the acromion.

From these latter 25 individuals, 16 were later identified as younger than 25 years of age. As such, the remaining nine individuals had *os acromiale*. Correspondingly, in these nine instances, the proximal end of the unfused acromion showed signs of slight bone remodelling and marginal lipping – a pattern previously described in cases of *os acromiale* (Yammine, 2014). It has been suggested that motions of the shoulder girdle stress the connection between both portions of an unfused acromion, leading to such degenerative changes (Prescher, 2000). In addition, the suspected cases of *os acromiale* showed signs of non-ossification between the meta- and meso-acromion, as the acromial angle was always present and yet the clavicular facet was always missing from the proximal end of the unfused acromia.

Regarding the ensuing sample, the age of included individuals ranged from 19 to 88 years, averaging 55.68. The mean age of the 40 male individuals was 55.73 (sd= 21.20) and of the 40 female individuals was 55.63 (sd= 21.20). Therefore, an equivalent age distribution was achieved between both sexes.

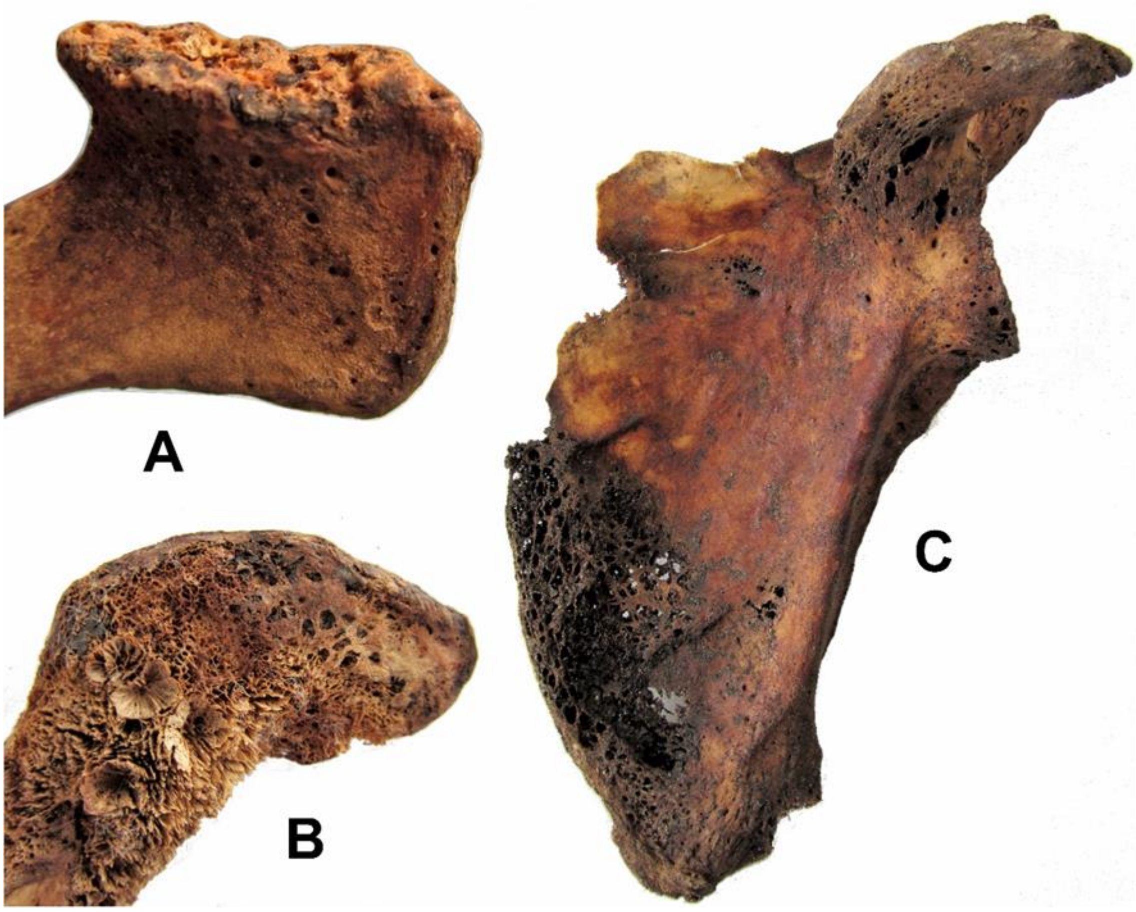

Figure 2.1 Examples of osteological specimens that were excluded from the study sample: Example A (MUHNAC.MB61-001204: caudal surface of acromion of left scapula) shows a unfused acromion with slight marginal lipping of the proximal portion and a missing distal portion; Example B (MUHNAC.MB61-001434: caudal surface of acromion of right scapula) reveals aggressive looking abnormal osteoblastic lesions, such as bony spicules and sunburst-shaped bony formations, that are usually related to malignant tumours; Example C (MUHNAC.MB61-001298: anterior surface of left scapula) presents an absent superior scapular angle, probably lost *post-mortem*. More flagrantly, the root of the coracoid process and especially the infero-medial region of the subscapular fossa expose widespread osteolytic lesions that mainly affect the cortical bone surface. At the subscapular fossa, these lesions reveal an ill-defined web of interconnected pits and trabeculae [Photographs by G. Fonseca ©ULisboa-MUHNAC].

2.2 Gross Inspection of Degenerative Changes in Scapulae

Every scapula (n= 160) was macroscopically inspected with the aid of magnifying glasses and a digital calliper (Mitutoyo 700-113-10 MyCAL-Lite; 0-150 mm; resolution of 0.1 mm; accuracy of +/-0.2 mm) by the same single blinded researcher who underwent more than 100 hours of specific training in assessing bony changes in scapulae.

2.2.1 Coracoacromial Enthesopathy

First, coracoacromial enthesophytes were assessed if protruding inferiorly, laterally and/or anteriorly from the anterior third of the acromion, laterally to the clavicular facet (Natsis et al., 2007; Nicholson et al., 1996; Oh, Kim, Lee, & Choi, 2010). Notably, osteoarchaeologists and paleopathologists have classified diverse enthesial changes due to their tremendous variation in overall appearance when observing enthesial footprints on dried bones (Henderson, Mariotti, Pany-Kucera, Villotte, & Wilczak, 2013, 2016; Henderson, Mariotti, Santos, Villotte, & Wilczak, 2017; Villotte et al., 2016; Villotte & Knüsel, 2013). As such, only clear enthesophytes were assessed in terms of presence and length of protusion due to their clinical relevance.

Accordingly, enthesophytes were defined as sharp to the touch and clear bony projections that displayed a non-native cortical architecture (Villotte et al., 2016). The length of protusion was defined as the distance from the point where the inclination of the acromial border abruptly increased to the tip of the enthesophyte (Ogawa, Yoshida, Inokuchi, & Naniwa, 2005). As such, enthesophytes were graded (1-4) according to their presence and length of protusion:

1. No enthesophyte: the enthesial footprint shows no signs of a clear enthesophyte, yet may show small bone formations, such as ill-defined bony protrusions, raised margins, and/or rough to the touch grainy surfaces that are difficult to measure. Likewise, the enthesial footprint may show signs of discontinuity, such as porosity, pitting, and/or cavitation.
2. Small enthesophyte: the enthesial footprint shows at least one clear enthesophyte reaching <5 mm in length of protrusion.
3. Medium enthesophyte: the enthesial footprint shows at least one clear enthesophyte reaching <10 mm in length of protrusion.
4. Large enthesophyte: the enthesial footprint shows at least one clear enthesophyte reaching ≥10 mm in length of protrusion.

All bony projections emerging from the margin of the clavicular facet were not regarded as coracoacromial enthesophytes, even if protruding from the anterior third of the acromion. They were instead judged as signs of acromioclavicular joint degeneration.

2.2.2 Glenohumeral Joint Degeneration

Second, the glenoid cavity was observed for signs of degeneration. Facet eburnation, pitting, osteophytes, and an altered bony contour (marginal lipping) were considered skeletal signs of joint degeneration (Jurmain & Kilgore, 1995; Nicholson et al., 1996; Oh et al., 2010; Ortner, 2003, pp. 546–554; Roberts et al., 2007; Rogers & Waldron, 1995, pp. 43–44; Shin et al., 2016; Steckel, Larsen, Sciulli, & Walker, 2011). Consequently, each specimen was graded (1-5) in accordance to the presence and extension of these signs, using an adapted assessment scale (Steckel et al., 2011, p. 32) and its accompanying pictured depictions (***Figure 2.2***):

1. No evidence of degenerative changes.
2. Slight marginal lipping (osteophytes less than about 3 mm) and slight degenerative or productive changes are present (left hand column: less than 50%, right hand column: more than 50%). No eburnation is present but the surface may include some porosity and pitting.
3. Severe marginal lipping (osteophytes greater than about 3 mm) and severe degenerative or productive changes are present. The white area in the drawing for grade 3 corresponds to eburnation, which is not essential if other degenerative aspects are severe. The surface may include substantial porosity and pitting.
4. Complete or near complete (more than about 80%) destruction of articular surface (margin and facet), including ankylosis.
5. Joint fusion (synostosis).

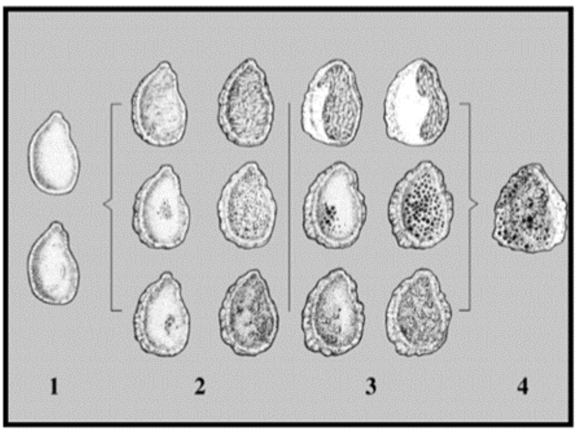

Figure 2.2 Representations of grades 1 through 4 of degenerative changes found on the glenoid cavity [illustration adapted from Steckel and colleagues (2011, p. 32)].

2.2.3 Acromioclavicular Joint Degeneration

Third, the clavicular facets of the acromia were also inspected for signs of degeneration. Due to the reduced size of these surfaces, no multileveled grading system was used. Instead, each clavicular facet was considered to show degeneration if eburnation or two or more of the other signs (pitting, osteophytes, and altered bony contour) were present (Roberts et al., 2007; Rogers & Waldron, 1995).

2.2.4 Intra-Rater Reliability

A second evaluation of the above degenerative changes was performed on the sample by the same researcher, two weeks after the first assessment, to determine test-retest reliability via the calculation of Cohen's Kappa coefficient (*K*) and rate of disagreement (*rd*).

2.3 Morphometric Study of Scapulae

Once gross evaluations were completed, all right scapulae in the sample (n= 80) were orthogonally photographed (Canon PowerShot SX600 HS; 16.0 megapixels; portrait mode; grids on; zooming off; flash off) in the lateral and posterior planes.

Each right scapula was secured in a retort stand with rubber clamps. The superior and inferior rims the glenoid cavity were oriented perpendicularly to the horizontal plane (Craik, Mallina, Ramasamy, & Little, 2014). Also, a self-levelling cross line laser device (Stanley Cubix STHT1-77340) was used to ensure that the lateral border of each right scapula, inferior to glenoid cavity, was set perpendicularly to the horizontal plane (***Figure 2.3***). Finally, the centre of every glenoid cavity was set at a fixed height of 15 cm.

In all pictures, the camera was secured on a support base with the lens set at the same height as the centre of the glenoid cavity (15 cm). In lateral perspective photographs, the support base was placed 12.5 cm from the lateral edge of the acromion, while pointing the lens towards the centre of the glenoid cavity. In posterior perspective photographs, the support base was set 26 cm from the body of the scapula, at a perpendicular angle.

The photographs were then analysed on the freeware image analysis software *ImageJ* (https://imagej.nih.gov/ij/) to study acromial morphology (Crahim et al., 2013; Craik et al., 2014), by measuring several pre-determined distances (***Figure 2.4***).

Figure 2.3 Usage of the self-levelling cross line laser device to ensure correct scapular placing for the photographic study. While a perfect positioning was utopic, it is observable on the right image that the scapula was placed in a more optimal position when compared to the left image. On the right image, the lateral border of the scapula, inferior to the glenoid cavity, is less anteriorly tilted and more perpendicular to the horizontal plane.

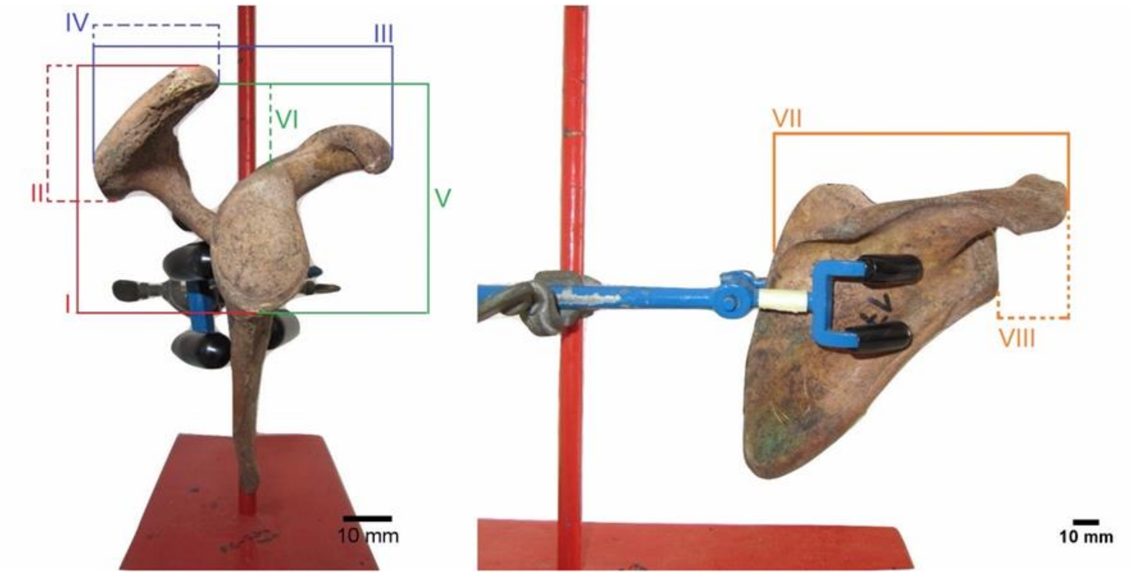

Figure 2.4 Distances measured on the lateral and posterior planes of all right scapulae in the sample: (I) acromioglenoid infero-superior length: vertical distance between the most superior point of the acromion and the infraglenoid tubercle; (II) acromial infero-superior length: vertical distance between the most superior and inferior points of the acromion; (III) acromiocoracoid postero-anterior length: horizontal distance between the most posterior point of the acromion and most anterior point of the coracoid process; (IV) acromial postero-anterior length: horizontal distance between the most posterior and anterior points of the acromion; (V) glenohumeral joint space: vertical distance between the most superior point of the caudal surface of the acromion and the infraglenoid tubercle; (VI) subacromial space: vertical distance between the most superior point of the caudal surface of the acromion and the supraglenoid tubercle; (VII) scapular spine medio-lateral length: horizontal distance between medial border of the scapula, at the level of the root of the spine of the scapula, and the most lateral point of the acromion; (VIII) acromial medio-lateral length: horizontal distance between the infraglenoid tubercle and the most lateral point of the acromion.

2.4 Statistical Analysis

The initial analysis of the collected data involved an appraisal of the frequencies of the three assessed types of degenerative changes (coracoacromial enthesophytes; glenohumeral joint degeneration; acromioclavicular joint degeneration) in the 160 inspected scapulae. Descriptive statistics were obtained to illustrate how each of these individual frequencies varied according to sex, age, body side, and according to the presence of the other degenerative changes. The graded magnitude of the enthesophytes and signs of glenohumeral joint degeneration was considered during the production and assessment of illustrative stacked bar charts.

Furthermore, the frequencies were summarized and introduced into 2 X 2 contingency tables to define each studied association. Yule's Q tests (*Q*) were calculated to assess the direction and strength of each association. Next, multiple Fisher's exact tests were used to assess the statistical significance of each association.

The second part of the statistical analysis involved the examination of the eight quantitative measurements that composed the study of morphology in the 80 right scapulae of the sample. Therefore, descriptive statistics were used to review the morphometric data collected on the right scapulae both before and after the scapulae were split into two independent groups, according to age, sex, and enthesophyte absence (grade 1) or presence (grade >1). Then, Student's t-tests were used to assess significant differences between groups.

The distribution of results across each of the eight quantitative measurements, in both groups (with and without enthesophytes), was visually assessed via box plot charts. In all results, outliers were removed and normality of distribution was confirmed through Shapiro-Wilk tests. Afterward, Point Biserial Correlation tests (r_{pb}) were calculated to quantify the direction and strength of the association between each morphometric measurement and the presence/absence of enthesophytes.

In all inferential tests, the alpha level of significance was predetermined at 0.05. Moreover, the results in both tests of association (*Q* and r_{pb}) ranged from -1 to 1, where -1 indicated a perfect negative association, 1 indicated a perfect positive association, and 0 meant no association.

All descriptive and inferential statistical analysis were performed using the spreadsheet software *Microsoft Excel 2016* (https://products.office.com/en-us/excel) in conjunction with the free add-in *Real Statistics Resource Pack*, release 5.0 (http://www.real-statistics.com).

3 RESULTS AND DISCUSSION

3.1 Degenerative Changes in Scapulae

Examination of the 160 scapulae of the sample revealed a very wide range of shapes and magnitudes of enthesophytes (***Figure 3.1***), acromioclavicular degenerative changes (***Figure 3.2***), and glenohumeral degenerative changes (***Figure 3.3***). Conversely, despite the large number of studied scapulae, there were no signs of glenohumeral degeneration concomitant with grade 5 (joint fusion) of the assessment scale (Steckel et al., 2011, p. 32). More importantly, intra-rater test-retest reliability scores were good for the assessment of acromioclavicular (*K*= 0.85; *rd*= 0.08) and glenohumeral (*K*= 0.70; *rd*= 0.18) degeneration and moderate for the assessment of enthesial changes (*K*= 0.66; *rd*= 0.22).

3.1.1 Coracoacromial Enthesopathy

Every scapula was analysed for signs of coracoacromial enthesopathy (***Figure 3.1***). Consequently, the inspection also revealed sites of remodelled bone (with signs of both abrasive lesions, namely pitting, and osteoblastic reactions, including eburnation) on the anterior third of the caudal surfaces of many acromia.

Seemingly, these features were positively related to the presence and size of enthesophytes. While all acromia with large enthesophytes (grade 4) exposed this bony change, acromia with no enthesophytes (grade 1) very rarely displayed this feature. However, this perceived association should be viewed with caution as a valid analysis of these small and subtle osteological signs was not possible in many borderline cases. Yet, when present and well-developed, these flattened surfaces of remodelled bone frequently acquired ovoid shapes and protruded inferiorly (no more than a couple millimetres) from the caudal surfaces of acromia and related enthesophytes. They were regularly outlined by marginal crests that appeared to be the osteophytic outcome of reactive bone formation, which occasionally gave these landmarks a concave aspect and a facet-like appearance (***Figure 3.4*** and example D in ***Figure 3.1***).

Other researchers have too observed varied bony features on the caudal surfaces of acromia (Edelson, 1995; Miles, 1996, 1999, 2000; Nicholson et al., 1996). Firstly, Graves (1922) described the presence of "plaques" on the caudal surfaces of acromia. Afterward, Gray (1942) described inferior "facets" on 22% of the acromia of a total 1085 analysed scapulae. Likewise, Neer (1972) himself reported that the "undersurface of the anterior process of the acromion" could also expose "erosion and eburnation". Finally, *Gray's Anatomy* (Standring et al., 2008, p. 795) references the existence of an "accessory articular facet on the inferior surface of the acromion".

Perhaps, these facet-resembling features of remodelled bone are a degenerative consequence of the superior humeral displacement that happens in overhead shoulder movements (Miles, 1999, 2000; Sharkey & Marder, 1995). The involved compressive forces may result in attrition and consequent periosteal osteoblastic reactions on the acromial caudal surface, since bone tissue dynamically adapts to mechanical stress (Chen, Liu, You, & Simmons, 2010; Frost, 1996, 2003; Ruff, Holt, & Trinkaus, 2006). Similarly, the repetitive increased strain on the coracoacromial ligament may facilitate gradual enthesopathy, ending in fibrosis and ossification, since the compressive forces result in fibroblast metaplasia, calcium deposition, and augmented fibrocartilage density in the ligament (Edelson & Taitz, 1992; Fealy et al., 2005; Rothenberg et al., 2017). Logically, it is admitted that subacromial bursae may suffer a similar degenerated fate (Miles, 2000; Villotte & Knüsel, 2013).

Furthermore, this degenerative process may be better understood through the lenses of Evolution, as different selective pressures often lead to divergent structural outcomes. For instance, in chimpanzees, Selection has favoured quadrupedal locomotion by terrestrial knuckle-walking. Accordingly, the prevalence of closed kinetic chain muscular actions with the upper limbs supports the importance of the rotator cuff complex. In chimpanzees, these scapulohumeral muscles must have relatively greater masses and force generation capacities for body weight bearing purposes (Potau et al., 2009).

Inversely, in humans, bipedalism triggered the liberation of upper limbs for distinct functions, particularly for carrying, manipulating, and throwing objects (Larson, 2007; Roach, Venkadesan, Rainbow, & Lieberman, 2013). Thus, such predominantly open kinetic chain actions resulted in a reduced functional relevance of rotator cuff muscles in body weight bearing, versus an overall increased importance of the deltoid muscle – inserted in a comparatively large acromion (Voisin, Ropars, & Thomazeau, 2014). In humans, the deltoid muscle acts against inferior humeral translation, relevant when the upper limb carries heavy loads for instance. Parallelly, the lower proportional size of rotator cuff muscles allows more precise and rapid movements of the shoulder joint, important for manipulative tasks (Potau et al., 2009).

Biomechanically, however, the virtual atrophy and reduced ability of the human rotator cuff muscles to stabilize the humeral head in the glenoid cavity during overhead shoulder movements, conducted primarily by the deltoid muscle, eases superior humeral translation and contact with the coracoacromial arch, which can be even more evident in cases of rotator cuff fatigue, altered kinematics, and injury (Chopp, O'Neill, Hurley, & Dickerson, 2010; De Witte et al., 2014; Henseler et al., 2014; Royer et al., 2009; Terrier, Reist, Vogel, & Farron, 2007).

Ultimately, this common pattern of motion in human shoulders has been deemed physiologic (Yamamoto et al., 2010). Likewise, the site of contact between the humeral head and coracoacromial arch has been termed a "neo-articulation" that is, nonetheless, incompatible with the currently long lifespan of humans (Voisin et al., 2014). Indeed, repetitive shoulder movements and the consequent increased compressive forces may substantiate the incidence of degenerative changes on both subacromial soft tissues and on the bony and ligamentous structures of the coracoacromial arch.

3.1.2 Glenohumeral and Acromioclavicular Joint Degeneration

Globally, the bony changes assessed on the joint surfaces of the scapulae in the sample were consistent with acromioclavicular (***Figure 3.2***) and glenohumeral (***Figure 3.3***) joint degeneration. For instance, the abrasive lesions (e.g. pitting) found on altered joint surfaces were only possible if covering tissues, namely cartilages, had been also deteriorated. Similarly, osteoblastic reactions (e.g. eburnation) were consequences of continuous mechanical stress on uncovered subchondral bone. Likewise, the presence of marginal osteophytes probably resulted from ossifications of the ligamentous and fibrous structures that formed the synovial capsules (Ortner, 2003, p. 546).

Even with obvious joint degenerative changes being evident on numerous scapulae, we could not assume the *ante-mortem* presence of pathological conditions, since we did not have access to fully detailed medical records of the subjects in our sample. More importantly, the sole examination of skeletal material does not enable an accurate palaeopathological diagnosis of multifactorial diseases, namely osteoarthritis, that also affect soft tissues and involve pain and disability (Jurmain & Kilgore, 1995).

Analogously, clinical research performed with living subjects has also cautioned that the presence of structural degenerative changes on joints is not a reliable primary indicator of debilitating pathologies. For example, there is no unambiguous association, much less a causative link, between signs of joint degeneration, verifiable through medical imaging techniques, and actual experiences of joint pain, swelling, and loss of function (Bedson & Croft, 2008; Finan et al., 2013; Sher, Uribe, Posada, Murphy, & Zlatkin, 1995).

Thus, there should be a clear distinction between the osteological and imaging concept of "joint degeneration" and the symptomatic disease that is "osteoarthritis". In a comparable manner, the presence of a coracoacromial enthesophyte, no matter how large or aggressive it may look, does not disclose the presence of a rotator cuff tear, though it may be considered a logical risk factor (Ogawa et al., 2005; Oh et al., 2010).

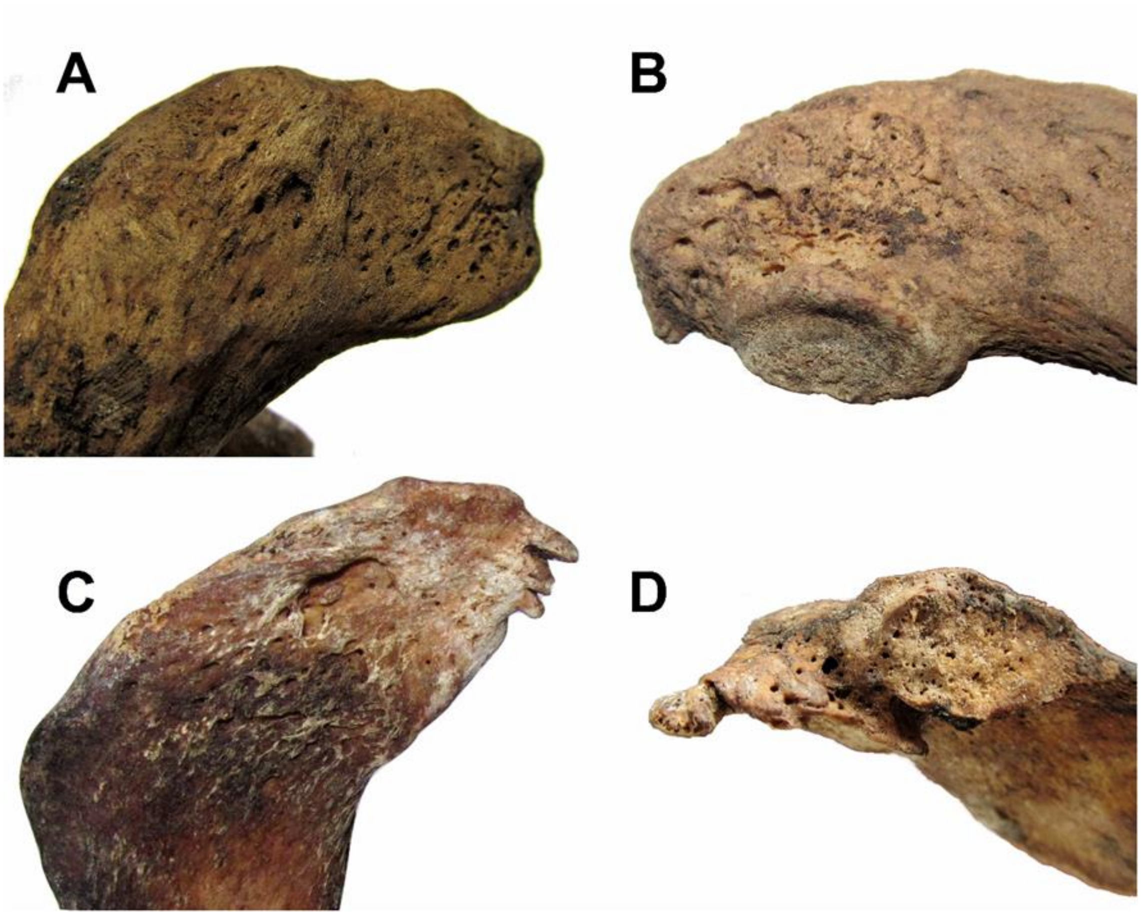

Figure 3.1 Four acromia, in different perspectives, representing different shapes and sizes that coracoacromial enthesophytes acquired: Example A (MUHNAC.MB61-000517: cranial surface of acromion of left scapula) shows no clear enthesophyte (grade 1) since its borders at the anterior third are smooth all around. The rounded prominences on the lateral acromial edge show a native homogenous cortical nature, thus probably being acromial tubercles for insertion of the deltoid muscle; Example B (MUHNAC.MB61-000335: medial border and cranial surface of acromion of right scapula) presents a small enthesophyte (grade 2) protruding inferiorly from the tip of the acromion, present anteriorly to the clavicular facet; Example C (MUHNAC.MB61-001296: caudal surface of acromion of right scapula) reveals a minimum of three distinguishable enthesophytes protruding antero-medially, with the largest one being a medium enthesophyte (grade 3); Example D (MUHNAC.MB61-000004: antero-medial outlook at the tip of acromion of right scapula) exhibits a large enthesophyte (grade 4) that projects anteriorly and displays abnormal cortical bone formation on its caudal surface. In addition, the clavicular facet is pitted and its margin is altered [Photographs by G. Fonseca ©ULisboa-MUHNAC].

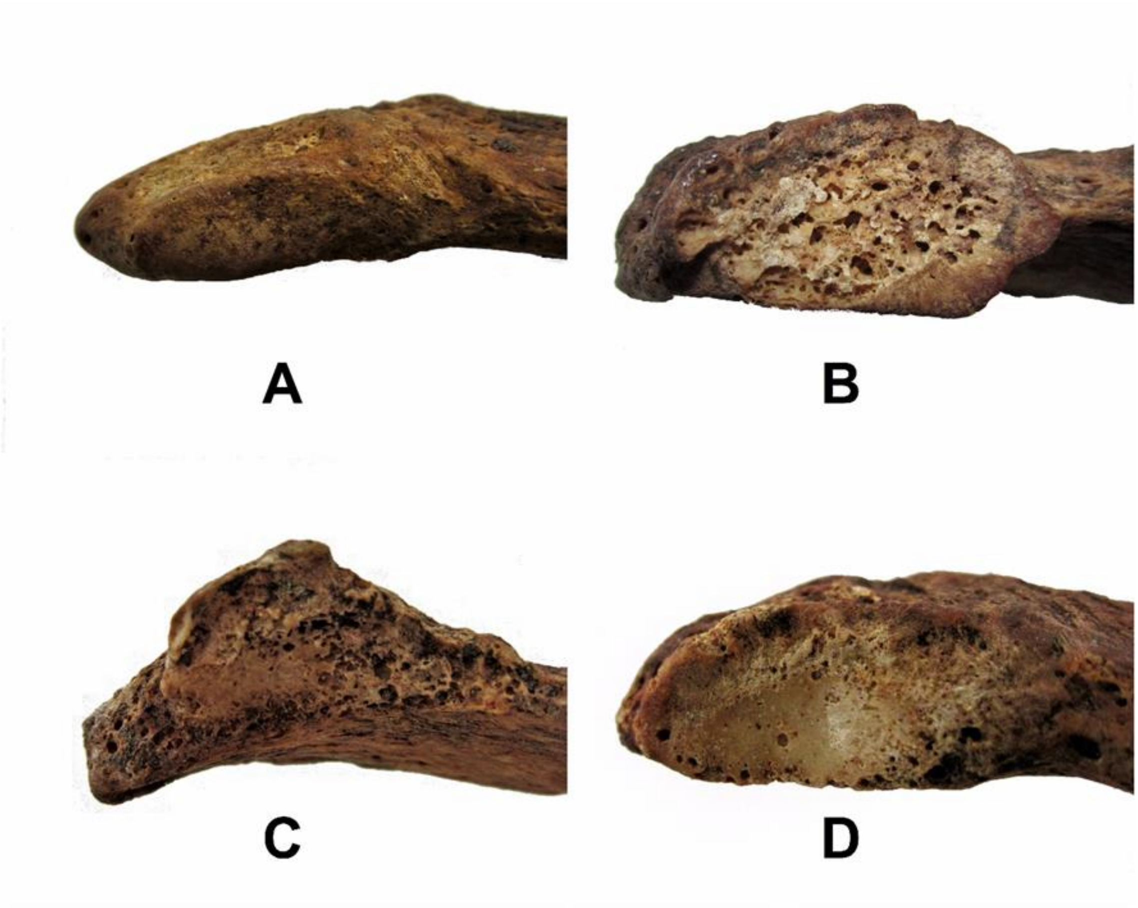

Figure 3.2 Medial surfaces of acromia of four right scapulae that illustrate diverse degenerative changes at the clavicular facet of the acromioclavicular joint: Example A (MUHNAC.MB61-000276) shows no degenerative changes as the joint facet is smooth and its margin is well defined; Examples B (MUHNAC.MB61-001404) and C (MUHNAC.MB61-001432) show clear degenerative changes since the clavicular facets show pitting and their margins are enlarged and irregular due to osteophytic activity; Example D (MUHNAC.MB61-001615) also shows degenerative changes with eburnation being easily identifiable on the clavicular facet, with its "smoothly polished appearance resembling that of porcelain" (Ortner, 2003, pp. 547–548) [Photographs by G. Fonseca ©ULisboa-MUHNAC].

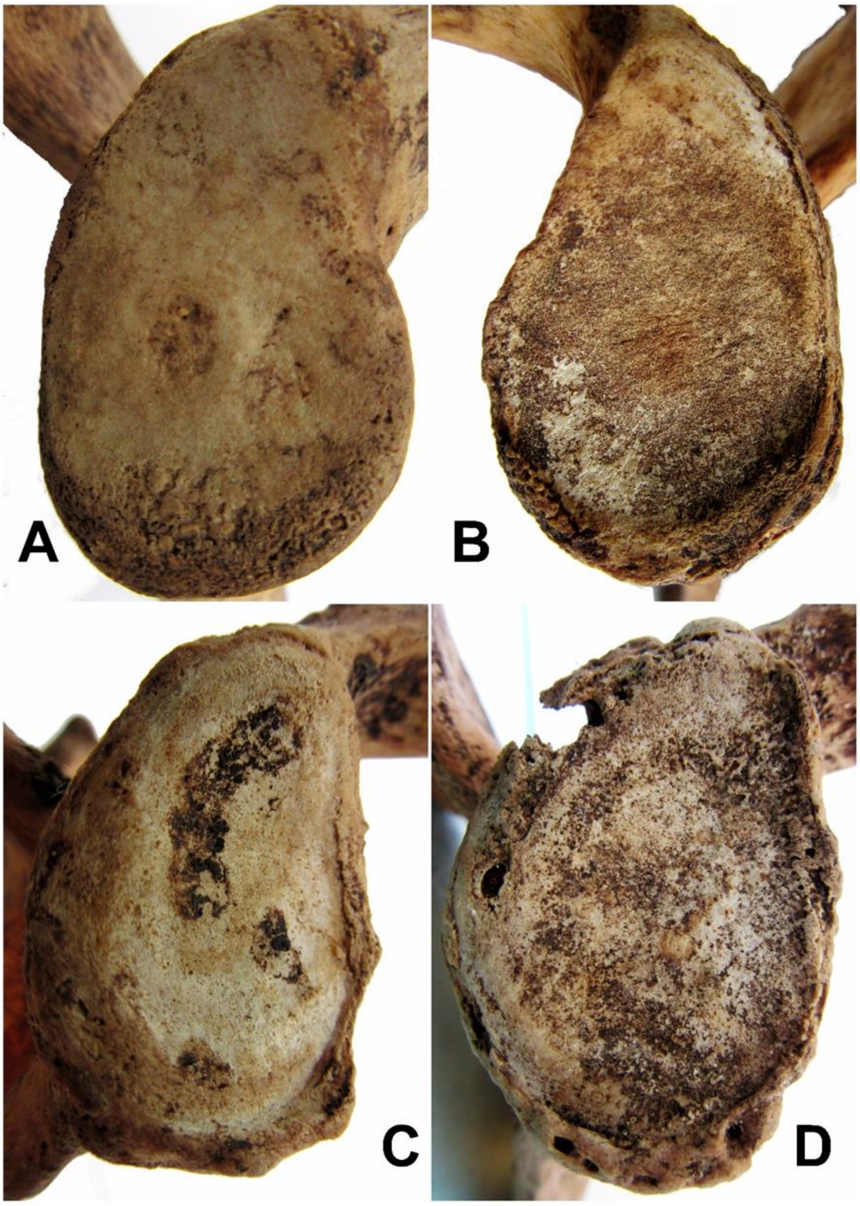

Figure 3.3 Glenoid cavities of four scapulae, demonstrating the several grades of degeneration found: Example A (MUHNAC.MB61-000276) shows no glenohumeral degeneration (grade 1) as the glenoid surface is smooth and its margin is very well defined; Example B (MUHNAC.MB61-001406) illustrates slight degenerative changes (grade 2) with the articular surface exhibiting some porosity and minor marginal lipping, with osteophytes projecting less than 3 mm; Example C (MUHNAC.MB61-001233) displays severe degenerative changes (grade 3). Attrition lesions are located on the articular facet, although no clear eburnation is found. Moreover, osteophytes projecting more than 3 mm are visible, particularly on the lower part of the glenoid rim; Example D (MUHNAC.MB61-000383) reveals the joint surface and margin completely covered with advanced degenerative changes (grade 4). The glenoid facet is completely covered with pits and the margin is enclosed by warping osteophytes. Overall, the facet surface and boundary are severely distorted [Photographs by G. Fonseca ©ULisboa-MUHNAC].

Figure 3.4 Latero-inferior view of glenoid cavity and coracoacromial complex in left scapula (MUHNAC.MB61-001233) showing an enthesophyte protruding from the anterior tip of the acromion. The caudal surface of the enthesophyte and of the near anterior acromion show an inferiorly protruding, ovoid, facet-resembling, flattened formation of remodelled bone that is surrounded by an irregular marginal crest [Photograph by G. Fonseca ©ULisboa-MUHNAC].

3.1.3 Associations between Degenerative Changes, Sex, Age, and Side

Regarding the calculated frequencies of each of the three studied types of degenerative changes, these did not show a significant association with a specific sex or body side (***Table 3.1***). Accordingly, our results are consistent with those described by Roberts and colleagues (2007). Their study included the analysis of osteological changes on scapulae, clavicles, and humeri belonging to a total of 74 sex-identified individuals. There was little difference in the frequency of degenerative changes, between right and left sides, and also no significant difference between males and females.

Alternatively, the presence of each studied degenerative change showed a significant positive association with increasing age (***Table 3.1***). Consequently, our results show that coracoacromial enthesophytes (Q= 0.67; p< 0.05), glenohumeral degeneration (Q= 0.97; p< 0.05), and acromioclavicular degeneration (Q= 0.96; p< 0.05) are normal degenerative manifestations that develop continuously with age. This notion was graphically confirmed because greater relative frequencies of degenerative changes were observed with increasing age (***Figure 3.5***). Furthermore, although the total relative occurrence of bony changes raised with age, it was also confirmed the incidence of small enthesophytes (grade 2) and minor signs of glenohumeral degeneration (grade 2) decreased after 75 years of age, being overlapped by progressively more pronounced degenerative changes (grades 3 and 4).

Unsurprisingly, the association of aging with the presence of these bony changes had been verified in multiple prior studies (Bonsell et al., 2000; Nicholson et al., 1996; Ogawa et al., 2005; Roberts et al., 2007; Rogers, Shepstone, & Dieppe, 2004). Indeed, aging relates to osteoblast, osteocyte, and osteoclast senescence which results in global alterations to bone remodelling, bone matrix composition, and bone morphological integrity (Boskey & Coleman, 2010; Marie, 2014). Likewise, aging is related to the ossification of ligamentous structures due to an increased mineral content in their extracellular environments (McCarthy & Hannafin, 2014; Osakabe et al., 2001).

The results also suggest that, not only each type of bony change develops with age, yet also co-develop alongside each other, as significant positive associations existed between them (***Table 3.1***). Specifically, the relationship between signs of acromioclavicular degeneration and coracoacromial enthesophytes had already been reported, yet not comprehensively studied. For example, Neer (1972), who first theorized the association of coracoacromial enthesophytes with sub-acromial impingement syndrome, also noticed "hypertrophic lipping at the acromioclavicular joint". Similarly, Edelson and Taitz (1992), who examined 200 dried scapulae for signs of coracoacromial arch degeneration, found not only enthesophytes but also "extensive degenerative changes on the acromial facet of the acromioclavicular joint".

Despite their anatomical proximity, the parallel occurrence of coracoacromial enthesophytes, glenohumeral degeneration, and coracoacromial degeneration matches the theory proposed by Rogers, Shepstone, and Dieppe (2004) in that osteological degenerative changes may be linked to a "systemic predisposition to a particular type of bone response to mechanical stress". In their study, 563 skeletons were assessed for signs of joint degeneration in the shoulders, elbows, wrists, hips, hands, knees, and ankles. Their findings indicated that, when present, skeletal signs of joint degeneration were widespread in the body and occurred in several joints simultaneously. Similarly, a strong relationship was found between joint degenerative changes and "generalized enthesophyte formation". Likewise, degenerative features, such as eburnation and osteophytes, became more prevalent with age at all studied joint sites. All in all, the theorized "systemic" nature of osteoarticular degeneration may be simply related to the expected bone cell senescence and ligamentous alterations that occur with aging (Boskey & Coleman, 2010; Marie, 2014; Osakabe et al., 2001).

Moreover, Rogers et al. (2004) reported that several joint sites not prone to osteoarthritis, such as the elbow and wrist, also displayed widespread degenerative changes regardless. Suitably, this latter observation further validates the necessity of distinction between physical joint degeneration and symptomatic joint disease. In a clinical scenario, the discordance between structural degeneration and disease, together with the positive association between aging and degenerative changes suggests that radiological examination in shoulder impairments "should be interpreted in the context of the symptoms and normal age-related changes" (Bonsell et al., 2000).

Table 3.1 Results of Yule's Q tests used to determine the strength and direction of each statistical association. Statistically significant associations (p< 0.05) are in **bold** and were determined via Fisher's exact tests.

	Presence of Enthesophytes		*Signs of ACJ Degeneration*		*Signs of GHJ Degeneration*	
	Yule's Q	*p value*	*Yule's Q*	*p value*	*Yule's Q*	*p value*
Presence of Enthesophytes	-	-	**0.74**	**< 0.05**	**0.83**	**< 0.05**
Signs of ACJ Degeneration	**0.74**	**< 0.05**	-	-	**0.95**	**< 0.05**
Signs of GHJ Degeneration	**0.83**	**< 0.05**	**0.95**	**< 0.05**	-	-
Age (>55)	**0.67**	**< 0.05**	**0.96**	**< 0.05**	**0.97**	**< 0.05**
Sex (Female)	0.27	0.11	0.05	0.87	0.05	0.87
Body Side (Left)	-0.08	0.75	0	1	-0.05	0.87

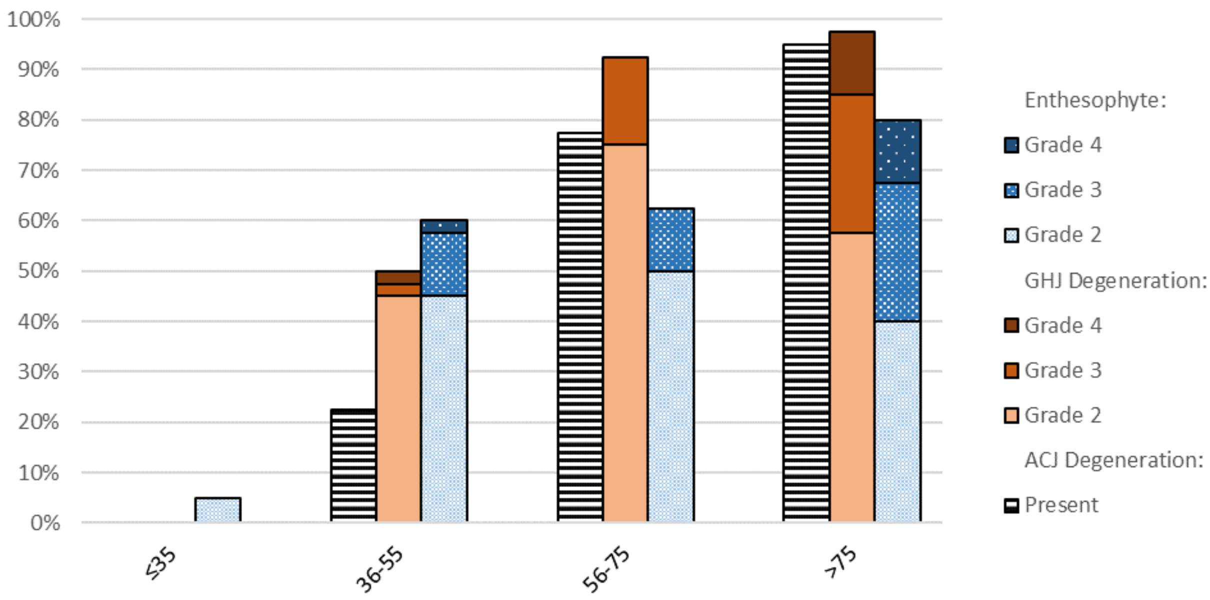

Figure 3.5 Percental frequencies of each type of studied degenerative changes across age groups. The different grades of enthesophytes and glenohumeral degenerative changes that were encountered are represented on the stacked columns.

3.2 Morphometry of Scapulae

Overall, traditional osteometric techniques (e.g. reliant on the use of callipers, tapes, boards, and goniometers) were deemed unsatisfactory to accurately quantity the tortuous anatomy of the entire acromial-glenoid-coracoid complex. Correspondingly, imaging methods previously applied to study the morphology of this anatomical region also displayed significant obstacles.

For example, Bigliani and colleagues (1986), were the first to subjectively classify the shape of the acromion in the sagittal plane, using outlet view radiographs. Subsequently, and to this day, the shape of acromia is still widely classified by both clinicians and researchers worldwide using the later updated Bigliani-Vanarthos system, as type I (flat), type II (curved), type III (hooked), or type IV (convex) (Bigliani et al., 1986; Vanarthos & Monu, 1995). For instance, researchers have tried to elucidate the relationship of the different acromial types to different shoulder impairments (Gagey, Ravaud, & Lassau, 1993; Gill et al., 2002; Toivonen, Tuite, & Orwin, 1995). In spite of its appealing simplicity and widespread use, the method developed by Bigliani and colleagues (1986) is highly subjective and has been criticized for its poor inter-rater reliability (Jacobson et al., 1995).

Subsequently, numerous authors have been developing a vast array of quantitative indices and angles to define the morphology of the acromial-glenoid-coracoid complex. Noteworthy examples include the acromial slope (Balke et al., 2013, 2016; Bigliani et al., 1991; Kitay et al., 1995; Vähäkari et al., 2010); acromial tilt (Balke et al., 2013, 2014; Kitay et al., 1995; Vähäkari et al., 2010); acromial index (Balke et al., 2013, 2014, 2016; Moor, Wieser, Slankamenac, Gerber, & Bouaicha, 2014; Nyffeler, Werner, Sukthankar, Schmid, & Gerber, 2006; Pandey et al., 2016); critical shoulder angle (Balke et al., 2016; Chalmers et al., 2017; Cherchi, Ciornohac, Godet, Clavert, & Kempf, 2016; Moor et al., 2014; Pandey et al., 2016); and lateral acromial angle (Balke et al., 2013, 2014, 2016; Banas, Miller, & Totterman, 1995; Moor et al., 2014).

Admittedly, these indices were primarily intended to be used on medical images (magnetic resonance images and radiographs), and some are inadequate to even apply on images of scapulae that are not *in situ*. Furthermore, the identification of most landmarks becomes a hindrance without the distinct view of bony contours, made possible through imaging technologies that are sensitive to differences in bone density. Also, the descriptions of some landmarks utilized in radiological indices lack in detail and clarity.

3.2.1 Associations between Morphology and Coracoacromial Enthesopathy

All in all, for this study, scaled photographs were used to define relevant scapular morphology. Hence, eight clearly defined morphometric parameters were measured: six on the lateral plus two on the posterior orthogonal planes of the 80 right scapulae in the sample (***Table 3.2***). Besides, three morphometric parameters showed significant associations with coracoacromial enthesopathy (***Table 3.3***).

Predictably, there were notorious differences in the mean measurements of every morphometric parameter when observing the results distributed according to sex (***Table 3.2***). Certainly, the scapula (and remaining shoulder girdle) is one of the elements of the human skeleton, besides the skull and pelvic girdle, that exhibits the most evident non-metric and metric signs of sexual dimorphism (Dabbs & Moore-Jansen, 2010; Escoval, 2016; Papaioannou, Kranioti, Joveneaux, Nathena, & Michalodimitrakis, 2012; Paulis & Samra, 2015; Scholtz & Steyn, 2010; Torimitsu et al., 2016).

Concomitantly, there were significant differences in the mean measurements of subacromial and glenohumeral joint spaces when observing the results distributed according to age (***Table 3.2***). Possibly, these reduced spaces in individuals aged over 55 years, could be interpreted together with the significant associations of enthesophyte incidence with age ($Q= 0.67$; $p< 0.05$), diminished subacromial ($r_{pb}= -0.22$; $p< 0.05$) and glenohumeral joint ($r_{pb}= -0.44$; $p< 0.05$) spaces.

Theoretically, innately reduced subacromial and glenohumeral spaces increase the tendency of repetitive contact between the humeral head and the coracoacromial arch, thus facilitating gradual enthesophyte formation. Inversely, small subacromial and glenohumeral joint spaces might be the secondary outcome of the facet-shaped bone formations that frequently protruded inferiorly from the caudal surfaces of acromia with enthesophytes.

Finally, the acromial postero-anterior length displayed a weak but positive association with enthesophyte presence ($r_{pb}= 0.23$; $p< 0.05$). This relationship was coherent since enthesophytes result from the proximal ossification of the coracoacromial ligament that projects anterio-inferiorly from the tip of the acromion to the lowered coracoid process. Therefore leading to an increased acromial sagittal curvature, resulting in a more curved/hooked bony structure (Edelson, 1995; Edelson & Taitz, 1992; Nicholson et al., 1996).

Table 3.2 Mean distance, in millimetres, of the eight morphometric parameters studied in the 80 right scapulae of the sample. The results are also exhibited according to age, sex, and presence of enthesophytes. Statistically significant differences ($p < 0.05$) are in **bold** and were determined via Student's t-tests.

	Total	*Age*		*Sex*		*Presence of Enthesophytes*	
		≤55	*>55*	*F*	*M*	*No*	*Yes*
	N= 80	*n= 40*	*n= 40*	*n= 40*	*n= 40*	*n= 37*	*n= 43*
(I) acromioglenoid infero-superior length	51.8	52.1	51.5	**49.9**	**53.7**	52.4	51.4
(II) acromial infero-superior length	28.5	28.2	28.9	**27.1**	**30.0**	28.3	28.7
(III) acromiocoracoid postero-anterior length	60.5	60.9	60.1	**57.6**	**63.4**	60.6	60.4
(IV) acromial postero-anterior length	31.1	30.3	31.9	**29.0**	**33.2**	**29.7**	**32.2**
(V) glenohumeral joint space	46.5	**47.2**	**45.8**	**44.6**	**48.5**	**47.4**	**45.8**
(VI) subacromial space	18.1	**19.1**	**17.1**	**17.4**	**18.8**	**19.2**	**17.2**
(VII) scapular spine medio-lateral length	129.2	128.4	130.0	**121.9**	**136.5**	128.7	129.7
(VIII) acromial medio-lateral length	32.4	32.9	32.0	**30.7**	**34.2**	32.3	32.5

Table 3.3 Results of Point Biserial Correlation tests (r_{pb}) used to determine the strength and direction of the statistical associations between each morphometric parameter and the presence of coracoacromial enthesophytes. Statistically significant associations ($p < 0.05$) are in **<u>bold</u>** and were determined via Student's t-tests.

	Presence of Enthesophytes	
	r_{pb}	*p value*
(I) acromioglenoid infero-superior length	-0.17	0.07
(II) acromial infero-superior length	0.05	0.33
(III) acromiocoracoid postero-anterior length	-0.03	0.39
(IV) acromial postero-anterior length	**<u>0.23</u>**	**<u>< 0.05</u>**
(V) glenohumeral joint space	**<u>-0.22</u>**	**<u>< 0.05</u>**
(VI) subacromial space	**<u>-0.44</u>**	**<u>< 0.05</u>**
(VII) scapular spine medio-lateral length	0.02	0.44
(VIII) acromial medio-lateral length	0.03	0.39

This page intentionally left blank.

4 CONCLUSIONS

Concluding, significant positive associations existed between advanced age (>55 years) and all types of studied degenerative changes, such as coracoacromial enthesophytes ($Q = 0.67$; $p < 0.05$), glenohumeral degeneration ($Q = 0.97$; $p < 0.05$), and acromioclavicular degeneration ($Q = 0.96$; $p < 0.05$). These relationships were reported on numerous prior studies and are the expected outcome of age-related senescence processes that alter bone cell function and ligament matrix. Concomitantly, the age-related co-occurrence of the diverse types of degenerative changes, unrelatedly to body side or sex, further corroborates the widespread and systemic nature of osteological degeneration. Clinically, a clear distinction should be made between osteological and imaging signs of age-related osteoarticular degeneration and symptomatic diseases, namely osteoarthritis.

Also, acromia with enthesophytes regularly displayed inferiorly protruding ovoid areas of remodelled bone on their caudal surfaces. These sites were considered the regions of contact between the humeral head and the coracoacromial arch during overhead shoulder movements. Indeed, these sites have been termed "neo-articulations" that seem mismatched with the currently long lifespan of humans. Long term, repetitive, and increased compressive forces in this pseudo-joint may help explain the degenerative changes on the bony and ligamentous structures of the coracoacromial arch.

Morphometrically, three parameters showed significant associations with coracoacromial enthesopathy. Understandably, the acromial postero-anterior length showed a positive association with enthesopathy ($r_{pb} = 0.23$; $p < 0.05$) as enthesophytes result from the proximal ossification of the coracoacromial ligament that projects anterio-inferiorly from the tip of the acromion. Basically, coracoacromial enthespathy does influence sagittal morphology of acromia. Also, there were significant associations of enthesopathy with both diminished subacromial ($r_{pb} = -0.22$; $p < 0.05$) and glenohumeral joint ($r_{pb} = -0.44$; $p < 0.05$) spaces. Perhaps, inherently small subacromial and glenohumeral spaces increase the tendency of repetitive contact between the humeral head and the coracoacromial arch, thus facilitating gradual enthesophyte formation. Otherwise, these reduced distances might be the secondary outcome of the measuring impact of the facet-shaped bone formations that frequently protruded inferiorly from the caudal surfaces of acromia with enthesophytes.

Despite the above conclusions, the current research faced some methodological limitations that must be cautiously taken into consideration when interpreting the results and following inferences.

First, the sample in this study was acquired from a single osteological collection. All subjects in the Luís Lopes collection lived and died between the 19th and 20th centuries and were collected from cemeteries across Lisbon, Portugal (Cardoso, 2006). Hence, the sample did not represent a wide bioanthropological spectrum, as most subjects were likely from European ancestry. More importantly, a fully detailed medical record of individuals was not attainable. Only cause of death was known. Having information regarding the *ante-mortem* incidence of shoulder diseases would be imperative for a valid investigation of clinical associations.

Second, the grading systems used to assess the presence and magnitude of acromioclavicular and glenohumeral degeneration were ultimately subjective. Similarly, the process of grading enthesial changes on dried bones was sometimes a grim task, particularly in borderline verdicts between small enthesophytes (grade 2) and more negligible formations of mineralised tissue, namely raised margins (grade 1). As such, despite being easily comprehensible, the methods of attribution of the different grades of degeneration were, at least, partially reliant on the skills, experience, and training of the assessor (Wilczak, Mariotti, Pany-Kucera, Villotte, & Henderson, 2017). Albeit the same single appraiser (G. Fonseca) conducted the physical inspection of all scapulae, an inter-rater reliability assessment was not performed.

Third, the morphometric study relied solely on the analysis of the right scapulae in the sample. On one hand, this number of scapulae was sufficient for a clear understanding of the association between different morphological parameters and the overall presence/absence of enthesophytes. On the other hand, comparing this relationship between body sides was not possible. In addition, Point Biserial Correlation tests could not be conducted without losing substantial statistical power, if other factors such as age and sex had been adjusted.

Finally, future studies on this topic should include, if possible, 3D morphometric analysis to better define the convoluted anatomy of the acromial-glenoid-coracoid region (Alobaidy & Soames, 2016). Similarly, humeri and clavicles ought to be study in conjunction with scapulae to allow a more complete view over bony changes and morphology on the entire shoulder girdle (Roberts et al., 2007). Equally, efforts should be made to better understand the nature of the degenerative features that commonly appear on the caudal surfaces of acromia, and thus to continue the work mainly developed by Miles (1996, 1999, 2000).

References

Alobaidy, M. A., & Soames, R. W. (2016). Evaluation of the coracoid and coracoacromial arch geometry on thiel-embalmed cadavers using the three-dimensional microscribe digitizer. *Journal of Shoulder and Elbow Surgery*, *25*(1), 136–141.

Balke, M., Banerjee, M., Vogler, T., Akoto, R., Bouillon, B., & Liem, D. (2014). Acromial morphology in patients with calcific tendinitis of the shoulder. *Knee Surgery, Sports Traumatology, Arthroscopy*, *22*(2), 415–421.

Balke, M., Liem, D., Greshake, O., Hoeher, J., Bouillon, B., & Banerjee, M. (2016). Differences in acromial morphology of shoulders in patients with degenerative and traumatic supraspinatus tendon tears. *Knee Surgery, Sports Traumatology, Arthroscopy*, *24*(7), 2200–2205.

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 Orthopaedica*, *84*(2), 178–183.

Banas, M. P., Miller, R. J., & Totterman, S. (1995). Relationship between the lateral acromion angle and rotator cuff disease. *Journal of Shoulder and Elbow Surgery*, *4*(6), 454–461.

Bedson, J., & Croft, P. R. (2008). The discordance between clinical and radiographic knee osteoarthritis: a systematic search and summary of the literature. *BMC Musculoskeletal Disorders*, *9*(1), 116.

Bigliani, L. U., Morrison, D. S., & April, E. W. (1986). The morphology of the acromion and its relationship to rotator cuff tears. *Orthopaedic Transactions*, *10*, 228.

Bigliani, L. U., Ticker, J. B., Flatow, E. L., Soslowsky, L. J., & Mow, V. C. (1991). The relationship of acromial architecture to rotator cuff disease. *Clinics in Sports Medicine*, *10*(4), 823–838.

Bonsell, S., Pearsall, A. W., Heitman, R. J., Helms, C. A., Major, N. M., & Speer, K. P. (2000). The relationship of age, gender, and degenerative changes observed on radiographs of the shoulder in asymptomatic individuals. *The Journal of Bone and Joint Surgery. British Volume*, *82*(8), 1135–1139.

Boskey, A. L., & Coleman, R. (2010). Aging and bone. *Journal of Dental Research*, *89*(12), 1333–1348.

Cardoso, H. F. V. (2006). Brief communication: the collection of identified human skeletons housed at the Bocage museum (National Museum of Natural History), Lisbon, Portugal. *American Journal of Physical Anthropology*, *129*(2), 173–176.

Chalmers, P., Salazar, D., Steger-May, K., Chamberlain, A., Yamaguchi, K., & Keener, J. (2017). Does the critical shoulder angle correlate with rotator cuff tear progression? *Clinical Orthopaedics and Related Research*, *475*(6), 1608–1617.

Chambler, A. F. W., & Emery, R. J. H. (1997). Acromial morphology: the enigma of terminology. *Knee Surgery, Sports Traumatology, Arthroscopy*, *5*, 268–272.

Chen, J.-H., Liu, C., You, L., & Simmons, C. A. (2010). Boning up on Wolff's law: mechanical regulation of the cells that make and maintain bone. *Journal of Biomechanics*, *43*(1), 108–118.

Cherchi, L., Ciornohac, J. F., Godet, J., Clavert, P., & Kempf, J. F. (2016). Critical shoulder angle: measurement reproducibility and correlation with rotator cuff tendon tears. *Orthopaedics and Traumatology: Surgery and Research*, *102*(5), 559–562.

Chopp, J. N., O'Neill, J. M., Hurley, K., & Dickerson, C. R. (2010). Superior humeral head migration occurs after a protocol designed to fatigue the rotator cuff: a radiographic analysis. *Journal of Shoulder and Elbow Surgery*, *19*(8), 1137–1144.

Codman, E. A. (1934). *The shoulder: rupture of the supraspinatus tendon and other lesions in or about the subacromial bursa.* Boston: Thomas Todd Copany.

Crahim, L. F., Nagato, A. C., Rocha, C. de L. J. V., Silva, M. A. dos S., Bandeira, A. C. B., Ferreira, T. A., & Bezerra, F. S. (2013). Acromial morphometric analysis using imaging software. *International Journal of Morphology*, *31*(1), 345–350.

Craig, E. V. (1986). Subacromial impingement syndrome in hereditary multiple exostoses. *Clinical Orthopaedics and Related Research.*, *209*, 182–184.

Craik, J. D., Mallina, R., Ramasamy, V., & Little, N. J. (2014). Human evolution and tears of the rotator cuff. *International Orthopaedics*, *38*(3), 547–552.

Dabbs, G. R., & Moore-Jansen, P. H. (2010). A method for estimating sex using metric analysis of the scapula. *Journal of Forensic Sciences*, *55*(1), 149–152.

De Witte, P. B., Henseler, J. F., Van Zwet, E. W., Nagels, J., Nelissen, R. G. H. H., & De Groot, J. H. (2014). Cranial humerus translation, deltoid activation, adductor co-activation and rotator cuff disease - different patterns in rotator cuff tears, subacromial impingement and controls. *Clinical Biomechanics*, *29*(1), 26–32.

Edelson, J. G. (1995). The "hooked" acromion revisited. *The Journal of Bone and Joint Surgery. British Volume*, *77*(2), 284–287.

Edelson, J. G., & Taitz, C. (1992). Anatomy of the coraco-acromial arch. Relation to degeneration of the acromion. *The Journal of Bone and Joint Surgery. British Volume*, *74*(4), 589–594.

Escoval, I. I. S. (2016). *Análise métrica do dimorfismo sexual da escápula na população Portuguesa: um novo método de diagnose sexual [Portuguese]*. Master Thesis in Human Biology and Evolution. Department of Life Sciences. University of Coimbra. Retrieved from http://hdl.handle.net/10316/33811

Fealy, S., April, E. W., Khazzam, M., Armengol-Barallat, J., & Bigliani, L. U. (2005). The coracoacromial ligament: morphology and study of acromial enthesopathy. *Journal of Shoulder and Elbow Surgery*, *14*(5), 542–548.

Finan, P. H., Buenaver, L. F., Bounds, S. C., Hussain, S., Park, R. J., Haque, U. J., … Smith, M. T. (2013). Discordance between pain and radiographic severity in knee osteoarthritis: findings from quantitative sensory testing of central sensitization. *Arthritis and Rheumatism*, *65*(2), 363–372.

Frost, H. M. (1996). Perspectives: a proposed general model of the "mechanostat" (suggestions from a new skeletal-biologic paradigm). *Anatomical Record*, *244*(2), 139–147.

Frost, H. M. (2003). Bone's mechanostat: a 2003 update. *Anatomical Record. Part A: Discoveries in Molecular, Cellular, and Evolutionary Biology*, *275*(2), 1081–1101.

Fujii, K., Takeda, Y., & Miyatake, K. (2015). Development of secondary ossification centres of the acromion in Japanese youth: a computed tomographic study. *Journal of Orthopaedic Surgery*, *23*(2), 229–233.

Gagey, N., Ravaud, E., & Lassau, J. P. (1993). Anatomy of the acromial arch: correlation of anatomy and magnetic resonance imaging. *Surgical and Radiologic Anatomy*, *15*(1), 63–70.

Gill, T. J., McIrvin, E., Kocher, M. S., Homa, K., Mair, S. D., & Hawkins, R. J. (2002). The relative importance of acromial morphology and age with respect to rotator cuff pathology. *Journal of Shoulder and Elbow Surgery*, *11*(4), 327–330.

Graves, W. W. (1922). Observations on age changes in the scapula: a preliminary note. *American*

Journal of Physical Anthropology, *5*, 21–33.

Gray, D. J. (1942). Variations in human scapulae. *American Journal of Physical Anthropology*, *29*, 57–72.

Henderson, C. Y., Mariotti, V., Pany-Kucera, D., Villotte, S., & Wilczak, C. (2013). Recording specific entheseal changes of fibrocartilaginous entheses: initial tests using the Coimbra method. *International Journal of Osteoarchaeology*, *23*(2), 152–162.

Henderson, C. Y., Mariotti, V., Pany-Kucera, D., Villotte, S., & Wilczak, C. (2016). The new "Coimbra Method": a biologically appropriate method for recording specific features of fibrocartilaginous entheseal changes. *International Journal of Osteoarchaeology*, *26*(5), 925–932.

Henderson, C. Y., Mariotti, V., Santos, F., Villotte, S., & Wilczak, C. A. (2017). The new Coimbra method for recording entheseal changes and the effect of age-at-death. *Bulletins et Mémoires de La Société d'Anthropologie de Paris*, 1–10. https://doi.org/10.1007/s13219-017-0185-x

Henseler, J. F., de Witte, P. B., de Groot, J. H., van Zwet, E. W., Nelissen, R. G. H. H., & Nagels, J. (2014). Cranial translation of the humeral head on radiographs in rotator cuff tear patients: the modified active abduction view. *Medical and Biological Engineering and Computing*, *52*(3), 233–240.

Jacobson, S. R., Speer, K. P., Moor, J. T., Janda, D. H., Saddemi, S. R., MacDonald, P. B., & Mallon, W. J. (1995). Reliability of radiographic assessment of acromial morphology. *Journal of Shoulder and Elbow Surgery*, *4*(6), 449–453.

Jurmain, R., & Kilgore, L. (1995). Skeletal evidence of osteoarthritis: a palaeopathological perspective. *Annals of the Rheumatic Diseases*, *54*(6), 443–450.

Kitay, G. S., Iannotti, J. P., Williams, G. R., Haygood, T., Kneeland, B. J., & Berlin, J. (1995). Roentgenographic assessment of acromial morphologic condition in rotator cuff impingement syndrome. *Journal of Shoulder and Elbow Surgery*, *4*(6), 441–448.

Larson, S. G. (2007). Evolutionary transformation of the hominin shoulder. *Evolutionary Anthropology*, *16*(5), 172–187.

Lugo, R., Kung, P., & Ma, C. B. (2008). Shoulder biomechanics. *European Journal of Radiology*, *68*(1), 16–24.

Marie, P. J. (2014). Bone cell senescence: mechanisms and perspectives. *Journal of Bone and*

Mineral Research, *29*(6), 1311–1321.

McCarthy, M. M., & Hannafin, J. A. (2014). The mature athlete: aging tendon and ligament. *Sports Health*, *6*(1), 41–48.

McMinn, R. M. H. (Ed.). (1990). *Last's anatomy - regional and applied.* (8th ed.). New York: Churchill Livingstone.

Miles, A. E. W. (1996). Humeral impingement on the acromion in a Scottish island population of c. 1600 AD. *International Journal of Osteoarchaeology*, *6*(3), 259–288.

Miles, A. E. W. (1999). Observations on the undersurface of the skeletalized human acromion in two populations. *International Journal of Osteoarchaeology*, *9*(2), 131–145.

Miles, A. E. W. (2000). Developing stages of subacromial humeral-impingement facets in the skeletal remains of two human populations. *International Journal of Osteoarchaeology*, *10*, 161–176.

Moor, B. K., Wieser, K., Slankamenac, K., Gerber, C., & Bouaicha, S. (2014). Relationship of individual scapular anatomy and degenerative rotator cuff tears. *Journal of Shoulder and Elbow Surgery*, *23*(4), 536–541.

Natsis, K., Tsikaras, P., Totlis, T., Gigis, I., Skandalakis, P., Appell, H. J., & Koebke, J. (2007). Correlation between the four types of acromion and the existence of enthesophytes: a study on 423 dried scapulas and review of the literature. *Clinical Anatomy*, *20*(3), 267–272.

Neer, C. S. (1972). Anterior acromioplasty for the chronic impingement syndrome in the shoulder: a preliminary report. *The Journal of Bone and Joint Surgery. American Volume*, *54*(A), 41–50.

Neer, C. S. (1983). Impingement lesions. *Clinical Orthopaedics and Related Research.*, *173*, 70–77.

Nicholson, G. P., Goodman, D. A., Flatow, E. L., & Bigliani, L. U. (1996). The acromion: morphologic condition and age-related changes. A study of 420 scapulas. *Journal of Shoulder and Elbow Surgery*, *5*(1), 1–11.

Nyffeler, R. W., Werner, C. M., Sukthankar, A., Schmid, M. R., & Gerber, C. (2006). Association of a large lateral extension of the acromion with rotator cuff tears. *The Journal of Bone and Joint Surgery. American Volume*, *88*(4), 800–805.

Ogata, S., & Uhthoff, H. K. (1990). Acromial enthesopathy and rotator cuff tear. A radiologic and histologic postmortem investigation of the coracoacromial arch. *Clinical Orthopaedics and Related Research*, *254*, 39–48.

Ogawa, K., Yoshida, A., Inokuchi, W., & Naniwa, T. (2005). Acromial spur: relationship to aging and morphologic changes in the rotator cuff. *Journal of Shoulder and Elbow Surgery*, *14*(6), 591–598.

Oh, J. H., Kim, J. Y., Lee, H. K., & Choi, J.-A. (2010). Classification and clinical significance of acromial spur in rotator cuff tear: heel-type spur and rotator cuff tear. *Clinical Orthopaedics and Related Research*, *468*(6), 1542–1550.

Ortner, D. J. (2003). *Identification of pathological conditions in human skeletal remains.* (2nd ed.). London, UK: Academic Press.

Osakabe, T., Hayashi, M., Hasegawa, K., Okuaki, T., Ritty, T. M., Mecham, R. P., … Seyama, Y. (2001). Age- and gender-related changes in ligament components. *Annals of Clinical Biochemistry*, *38*, 527–532.

Ozaki, J., Fujimoto, S., Nakagawa, Y., Masuhara, K., & Tamai, S. (1988). Tears of the rotator cuff of the shoulder associated with pathological changes in the acromion. A study in cadavera. *The Journal of Bone and Joint Surgery. American Volume*, *70*(8), 1224–1230.

Pandey, V., Vijayan, D., Tapashetti, S., Agarwal, L., Kamath, A., Acharya, K., … Willems, W. J. (2016). Does scapular morphology affect the integrity of the rotator cuff? *Journal of Shoulder and Elbow Surgery*, *25*(3), 413–421.

Papaioannou, V. A., Kranioti, E. F., Joveneaux, P., Nathena, D., & Michalodimitrakis, M. (2012). Sexual dimorphism of the scapula and the clavicle in a contemporary Greek population: applications in forensic identification. *Forensic Science International*, *217*(1–3), 231.e1-231e7.

Paulis, M. G., & Samra, M. F. A. (2015). Estimation of sex from scapular measurements using chest CT in Egyptian population sample. *Journal of Forensic Radiology and Imaging*, *3*(3), 153–157.

Potau, J. M., Bardina, X., Ciurana, N., Camprubí, D., Pastor, J. F., de Paz, F., & Barbosa, M. (2009). Quantitative analysis of the deltoid and rotator cuff muscles in humans and great apes. *International Journal of Primatology*, *30*(5), 697–708.

Prescher, A. (2000). Anatomical basics, variations, and degenerative changes of the shoulder joint and shoulder girdle. *European Journal of Radiology*, *35*(2), 88–102.

Quatrehomme, G., & Işcan, M. Y. (1997). Postmortem skeletal lesions. *Forensic Science International*, *89*(3), 155–165.

Roach, N. T., Venkadesan, M., Rainbow, M. J., & Lieberman, D. E. (2013). Elastic energy storage in the shoulder and the evolution of high-speed throwing in Homo. *Nature*, *498*(7455), 483–486.

Roberts, A. M., Peters, T. J., & Brown, K. R. (2007). New light on old shoulders: palaeopathological patterns of arthropathy and enthesopathy in the shoulder complex. *Journal of Anatomy*, *211*(4), 485–492.

Rogers, J., Shepstone, L., & Dieppe, P. (2004). Is osteoarthritis a systemic disorder of bone? *Arthritis and Rheumatism*, *50*(2), 452–457.

Rogers, J., & Waldron, T. (1995). *A field guide to joint disease in archaeology*. Chichester: John Wiley & Sons.

Rothenberg, A., Gasbarro, G., Chlebeck, J., & Lin, A. (2017). The coracoacromial ligament: anatomy, function, and clinical significance. *Orthopaedic Journal of Sports Medicine*, *5*(4), 2325967117703398. https://doi.org/10.1177/2325967117703398

Royer, P. J., Kane, E. J., Parks, K. E., Morrow, J. C., Moravec, R. R., Christie, D. S., & Teyhen, D. S. (2009). Fluoroscopic assessment of rotator cuff fatigue on glenohumeral arthrokinematics in shoulder impingement syndrome. *Journal of Shoulder and Elbow Surgery*, *18*(6), 968–975.

Ruff, C., Holt, B., & Trinkaus, E. (2006). Who's afraid of the big bad wolff?: "'Wolff's Law'" and bone functional adaptation. *American Journal of Physical Anthropology*, *129*, 484–498.

Scholtz, Y., & Steyn, M. (2010). A geometric morphometric study into the sexual dimorphism of the human scapula. *HOMO - Journal of Comparative Human Biology*, *61*(4), 253–270.

Sharkey, N. A., & Marder, R. A. (1995). The rotator cuff opposes superior translation of the humeral head. *The American Journal of Sports Medicine*, *23*(3), 270–275.

Sher, J. S., Uribe, J. W., Posada, A., Murphy, B. J., & Zlatkin, M. B. (1995). Abnormal findings on magnetic resonance images of asymptomatic shoulders. *The Journal of Bone and Joint Surgery. American Volume*, *77*(1), 10–15.

Shin, D. H., Jung, G.-U., Oh, C. S., Kim, M. J., Shin, E.-K., & Kim, Y.-S. (2016). Paleopathological patterns of degenerative arthropathy: prevalence of limb-joint osteoarthritis in Joseon people skeletons. *Anthropologist*, *24*(3), 702–710.

Soslowsky, L. J., An, C. H., Johnston, S. P., & Carpenter, J. E. (1994). Geometric and mechanical properties of the coracoacromial ligament and their relationship to rotator cuff disease. *Clinical Orthopaedics and Related Research.*, *304*, 10–17.

Standring, S., Borley, N. R., Collins, P., Crossman, A. R., Gatzoulis, M. A., Healy, J. C., … Wigley, C. (Eds.). (2008). *Gray's anatomy - the anatomical basis of clinical practice.* (40th ed.). Churchill Livingstone Elsevier.

Steckel, R. H., Larsen, C. S., Sciulli, P. W., & Walker, P. L. (2011). *Data collection codebook*. *The global history of health project - data collection codebook* (2nd ed.). Retrieved from global.sbs.ohio-state.edu/new_docs/Codebook-01-24-11-em.pdf

Terrier, A., Reist, A., Vogel, A., & Farron, A. (2007). Effect of supraspinatus deficiency on humerus translation and glenohumeral contact force during abduction. *Clinical Biomechanics*, *22*(6), 645–651.

Toivonen, D. A., Tuite, M. J., & Orwin, J. F. (1995). Acromial structure and tears of the rotator cuff. *Journal of Shoulder and Elbow Surgery*, *4*(5), 376–383.

Torimitsu, S., Makino, Y., Saitoh, H., Sakuma, A., Ishii, N., Yajima, D., … Iwase, H. (2016). Sex estimation based on scapula analysis in a Japanese population using multidetector computed tomography. *Forensic Science International*, *262*, 285e1-285e5.

Tubbs, R. S., Shoja, M. M., & Loukas, M. (Eds.). (2016). *Bergman's comprehensive encyclopedia of human anatomic variation*. New Jersey: John Wiley & Sons, Inc.

Vähäkari, M., Leppilahti, J., Hyvönen, P., Ristiniemi, J., Päivänsalo, M., & Jalovaara, P. (2010). Acromial shape in asymptomatic subjects: a study of 305 shoulders in different age groups. *Acta Radiologica*, *51*(2), 202–206.

Vanarthos, W. J., & Monu, J. U. V. (1995). Type 4 acromion: a new classification. *Contemporary Orthopaedics*, *30*, 227–229.

Villotte, S., Assis, S., Cardoso, F. A., Henderson, C. Y., Mariotti, V., Milella, M., … Jurmain, R. (2016). In search of consensus: terminology for entheseal changes (EC). *International Journal of Paleopathology*, *13*, 49–55.

Villotte, S., & Knüsel, C. J. (2013). Understanding entheseal changes: definition and life course changes. *International Journal of Osteoarchaeology*, *23*(2), 135–146.

Voisin, J. L., Ropars, M., & Thomazeau, H. (2014). The human acromion viewed from an evolutionary perspective. *Orthopaedics and Traumatology: Surgery and Research*, *100*(8), S355–S360.

White, T., Black, M. T., & Folkens, P. A. (2011). *Human osteology* (3rd ed.). Academic Press.

Wilczak, C. A., Mariotti, V., Pany-Kucera, D., Villotte, S., & Henderson, C. Y. (2017). Training and interobserver reliability in qualitative scoring of skeletal samples. *Journal of Archaeological Science: Reports*, *11*, 69–79.

Yamamoto, N., Muraki, T., Sperling, J. W., Steinmann, S. P., Itoi, E., Cofield, R. H., & An, K. N. (2010). Contact between the coracoacromial arch and the rotator cuff tendons in nonpathologic situations: a cadaveric study. *Journal of Shoulder and Elbow Surgery*, *19*(5), 681–687.

Yammine, K. (2014). The prevalence of os acromiale: a systematic review and meta-analysis. *Clinical Anatomy*, *27*(4), 610–621.