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The anatomy and variation of the coracoid attachment of the subclavius muscle in humans

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Abstract

The functions of the subclavius muscle (SM) are described as stabilization of the sternoclavicular joint (SCJ) and resisting elevation of the lateral end of the clavicle. During systematic cadaveric dissections, we observed additional fibrous structures, previously described as variants of the anatomy, extending from the SM and inserting into the coracoid process (CP). Due to the high incidence of these structures in our dissections, we hypothesized that the attachment at the CP is more common than appreciated and that, as a corollary, the function of the SM was (or has been) more complex than simply depressing the clavicle and generating stability at the SCJ. For our investigation, fifty-two upper extremities of 26 human cadavers were dissected. The SM was demonstrated from costal to clavicular attachment. We documented additional fibrous structures apparently derived from the SM inserting into the CP. Measurements of the length of the SM, the length of its attachment, and the length of the clavicle were taken in situ, with the specimens supine and the upper extremity in the anatomical position. Variations in the anatomy of the SM and its coracoidal attachment were recorded, and potential correlations were investigated. For documentation purposes photographs and video sequences of passive motion of the shoulder girdle of the specimens were taken. In 49 of the 52 specimens we found additional fibrous structures passing from the SM to the CP. We differentiated three types: (1) a strong cord-like structure; (2) a small or thin cord-like structure or structures; and (3) a planar twisted sheet-like structure. The SM and its extension to the CP appears to contribute to a 'functional scapular suspension system' together with the other muscles enveloped by the clavipectoral fascia (pectoralis minor, coracobrachialis and the short head of the biceps brachii). This system assists in the control of the position of the scapula in relation to the thorax, particularly in elevated positions of the upper extremity. We speculate that the differentiation of the fibrous structure depends on the functional demands of the individual.

Level of Evidence: Basic science study.

KEYWORDS
coracoid attachment, functional unit, musculoskeletal system, scapula, subclavius muscle proximal and distal attachment, upper extremity

1 | INTRODUCTION

While the gross anatomy of the subclavius muscle (SM) has been described (Bergman, 2014; Benninghoff, 1985; Eisler, 1912; Lanz, 1959; Mori, 1964; Platzer, 1999; Rauber, 1987; Standring & Tunstall, 2016), a detailed comprehension of its relationship to the clavipectoral fascia and coracoid process (CP) appears less well-documented. A comprehension of the musculotendinous anatomy of the SM and the clavipectoral fascia may be important in the analysis of clinical syndromes of neural compression (neurogenic thoracic outlet syndrome; Hasan & Romeo, 2001; Muellner, 2015; Ozcakar et al., 2010; Piyawinijwong & Sirisathira, 2010; Rani & Srivastava, 2014; Smayra et al., 2014). Its relevance to safe instrumentation of the subclavian vein has been documented (Lusskin et al., 1967; McCleery et al., 1951). The anatomy of the intrinsic tendon structure of the SM has been described (Bergman, 2014; Benninghoff, 1985; Eisler, 1912; Lanz, 1959; Mori, 1964; Platzer, 1999; Rauber, 1987; Standring & Tunstall, 2016) and its potential value as an augmentation for reconstruction of the costoclavicular ligament for sternoclavicular instability has been recognized (Burrows, 1951; Cave & Brown, 1952; Lunseth et al., 1975).

The function of the SM in humans has however remained obscure. Comparative non-human primate anatomical studies have suggested that the SM functions to regulate or control upper extremity motion (Konstant et al., 1982) rather than primarily as a stabilizer of either the sternoclavicular or acromioclavicular joints (Benninghoff, 1985; Platzer, 1999; Rauber, 1987; Standring & Tunstall, 2016). In other primate studies the SM is described as having a muscular extension to the CP (Konstant et al., 1982), while several descriptions of anatomical variations (largely duplications) of the SM in humans have been reported (Bergman, 2014; Eisler, 1912; Lanz, 1959; Mori, 1964; Platzer, 1999; Rauber, 1987; Standring & Tunstall, 2016). The subclavius posticus is the commonest variation reported (Bergman, 2014; Eisler, 1912; Lanz, 1959; Rauber, 1987): this aberrant muscle may play a role in more proximal thoracic outlet syndrome (Hasan & Romeo, 2001; Lusskin et al., 1967; McCleery et al., 1951; Ozcakar et al., 2010; Piyawinijwong & Sirisathira, 2010; Smayra et al., 2014).

The classic descriptions of the gross anatomy of the SM in humans concur that it attaches at the junction of the first rib and first costal cartilage (Benninghoff, 1985; Bergman, 2014; Eisler, 1912; Lanz, 1959; Mori, 1964; Platzer, 1999; Rauber, 1987; Schünke, 2005; Standring & Tunstall, 2016), immediately lateral to the costoclavicular ligament (Cave, 1961). The SM inserts on the inferior surface of the clavicle in a bony groove, the *sulcus m. subclavii*, limited laterally by the conoid tubercle and terminating between the coracoclavicular (CC) ligaments (Benninghoff, 1985; Eisler, 1912; Lanz, 1959; Mori, 1964; Platzer, 1999; Rauber, 1987; Standring & Tunstall, 2016). An additional, variable, attachment on to the CP has also been described (Bergman, 2014; Eisler, 1912; Lanz, 1959; Mori, 1964; Standring & Tunstall, 2016). In one description the lateral part of the SM was separated into a superomedial part inserted into the inferior surface of the clavicle and an inferolateral part inserted on to the root of the CP in 12 (16.8%) of 72 cases (Mori, 1964). Absence of the SM has been described (Crerar, 1892; Georgiev & Jelev, 2009; Le Double, 1897; Yun et al., 2018). In one of these reports, bilateral fibrous bands replaced the usual SM and were attached to the tip of the CP laterally (Georgiev & Jelev, 2009).

During a surgical anatomy programme conducted at the Division of Clinical and Functional Anatomy at the Medical University of Innsbruck we noted, in many dissections, additional fibrous structures contiguous with, and extending from, the SM epimysial fascia inserting into the base, medial margin and tip of the CP. This observation, suggested (1) that anatomical variations of the coracoid attachment of the SM are more common than previously reported, and (2) that the function of the SM is more subtle than simply that of stabilizing the clavicle at the sternoclavicular joint (SCJ; Benninghoff, 1985; Platzer, 1999; Rauber, 1987; Standring & Tunstall, 2016). Furthermore, the fact that the SM has a discrete nerve supply supports the notion that the SM has (or had) a more important role in the function of the upper extremity than conventionally considered.

The aim of this study, stimulated by the observation of the unexpected frequency of these often robust fibrous structures, was primarily to dissect the SM in a number of individuals to determine the extent and variability of the lateral extension(s) and attachment(s) of the muscle and its relationship to the CP.

2 | MATERIALS AND METHODS

Embalmed human cadavers, preserved using an arterial injection of a formaldehyde-phenol solution and immersion in phenolic acid in water for 1–3 months (Platzer & Poisel, 1978), were used. The bodies were donated to the Division of Clinical and Functional Anatomy at the Medical University of Innsbruck, Austria, following pre-mortem informed consent for their use in scientific studies (M^c^Hanwell et al., 2008; Riederer et al., 2012). The specimens were all of Central European Caucasian origin: anatomical variations due to different ethnicity were not expected. We investigated 52 upper extremities of 26 human cadavers (14 female and 12 male). The mean age of the specimens was 78 years (range: 58–93): the mean age for female specimens was 79 years (range: 58–92) and for males 77 years (range: 59–93). The mean height of the 25 specimens in which this was possible to measure was 168.4 cm (range: 150–185; female, mean 164 cm, range: 150–172; male, mean 173 cm, range: 160–185).

2.1 | Anatomical preparation

After desquamation, the pectoralis major and deltoid muscles were exposed (Figure 1a). The clavicular and upper sternal part of the pectoralis major muscle and the clavicular attachment of the deltoid muscle were detached to expose the clavipectoral fascia enveloping the subclavius and pectoralis minor muscles. The proximal attachment of the SM was exposed at the osteocartilaginous junction of the first rib. The attachment fibres of the fibrous expansion of the SM to the CP were identified and preserved for measurement when present. The attachment of the SM into the sulcus M. subclavii was demonstrated after opening the clavipectoral fascia and subsequently the SM epimysial fascia (Figures 1–3).

The following dimensions were recorded: (1) the axial (apparent) length of the clavicle (from the anterior rim of the sternal facet of the clavicle in the midline of the shaft to the anterior rim of the acromial facet in the midline of the shaft); (2) the (real) length of the clavicle measured between the two points given but on the external curved surface of the bone; (3) The overall length of the SM (muscular part and fibrotic extension) was measured from the lateral extent of its proximal attachment on the first rib to (a) the coracoid (midpoint of the coracoid tip) and (b) the lateral end of the attachment in the sulcus m. subclavii; (4) the length of the attachment of the SM in the sulcus M subclavii (measuring from the beginning of the insertion of the muscle fibres at the clavicular surface to the end of the insertional fibres at the lateral end of the sulcus m. subclavii); (5) the distance from the proximal attachment of the SM on the first rib (at the cartilago costalis, the costosternal junction) at which the nerve to the SM entered the muscle; and (6) the distance, as defined for the nerve, at which the artery to the muscle entered the muscle where this was possible. Three independent observers performed measurements to the nearest millimetre using a steel engineering rule and measuring tape. The mean of the three measurements was calculated. Observed variations in the extent and dimensions of the proximal and distal attachment of the SM were recorded. Variations in the gross anatomy of the SM including duplications were noted. An estimation of overall curvature of the clavicle was calculated by comparison of the two length measurements expressed as a ratio, a larger ratio being indicative of greater overall curvature (medial antecurve and lateral retrocurve combined) of the clavicle.

Measurement data were entered into an Excel spreadsheet (Microsoft Office 2010; Excel 14.6.6) and recorded as mean values, and minima and maxima. The dissection sequences were photographed at intervals for documentation purposes. Video sequences of passive motion of the shoulder girdle observing the dynamic relationship between the coracoid, clavicle and SM were recorded for later assessment (and are the subject of a separate report).

Potential correlations between the presence and form of the extension aponeurosis of the SM and age, gender, height, side, clavicular curvature, clavicular length and SM muscle length were assessed. Statistical analysis was performed with the statistical program SPSS for Windows, version 11.5 (SPSS).

3 | RESULTS

Two (male) clavicles had united midshaft fractures, both on the left side. These specimens were not assessed for the ratio of curvature, nor for the length or dimensions of the SM attachment or for the entry point of neurovascular supply to the muscle.

The anatomy of the muscular part of the SM was variable: there were two specimens (one female, one male) with an additional muscular belly, both on the left side, inserting into the superior border of the scapula adjacent to the distal attachment of the omohyoideus muscle, consistent with the nomenclature of a subclavius posticus. In seven specimens there was an additional muscular attachment to

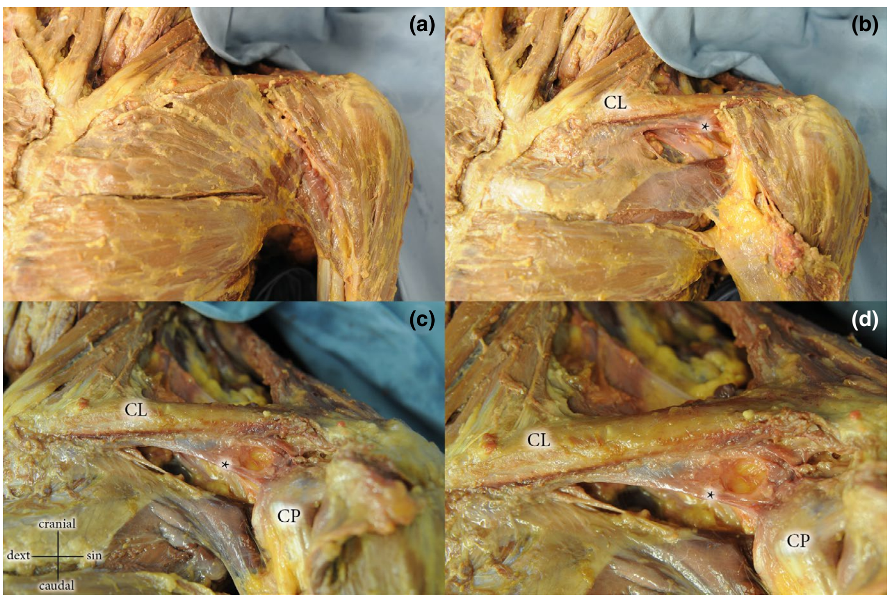

FIGURE 1 Anterior view. (a–d): sequential dissection of the anterior-superior chest wall structures to expose the subclavius. (a) Desquamation, removal of subcutaneous fat and muscle fascia over the pectoralis major and deltoid muscles. (b) The pars clavicularis and the upper part of the pars sternoclavicularis of the pectoralis major are separated. The clavipectoral fascia is partially opened. The SM and fibrous expansion to the coracoid process are seen (*). (c and d): The pars clavicularis of the deltoid muscle is detached. The tendon of the short head of biceps muscle is seen attached to the coracoid process: the thin planar (in this case) expansion of the SM to the coracoid process is readily seen (*)

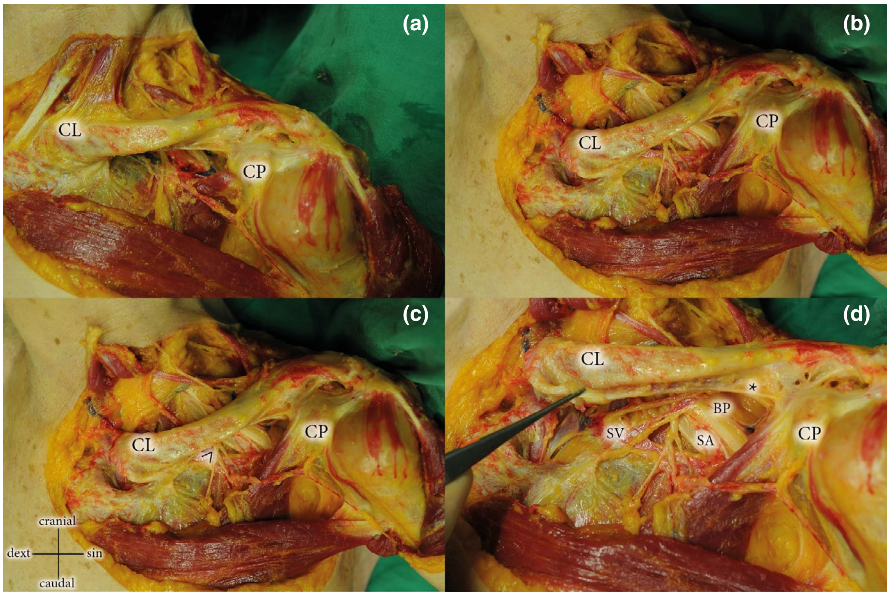

FIGURE 2 Dissections showing changes in the orientation, shape and form of the structures related to the clavicle during passive motion of the shoulder girdle. (a) The left shoulder girdle is seen from in front: the clavicular part of the pectoralis major and deltoid muscle have been removed. The shoulder girdle is caudally translated. The pectoralis minor muscle is lax. (b and c) The left upper extremity is cranially translated (passively elevated). By comparison with (a), both the pectoralis minor muscle and the tendinous structure from the SM attaching at the CP are under apparent tension. The arthrotomy of the sternoclavicular joint shows the medial attachment of the SM at the first rib. The brachial plexus, subclavian vein and artery, and the pectoralis minor nerve supply are seen deep to the clavicle. (d) the medial attachment of the SM to the first rib has been sectioned and the medial clavicle has been elevated to give a better view of the structures deep to the clavicle. The structures attaching to the CP: the fibres of the SM aponeurosis, the coracoclavicular ligaments, the coracoacromial ligament, the tendon of the coracobrachialis and the pectoralis minor attachment are all readily noted. (a–d) CL, clavicle; CP, coracoid process. (c) >, pectoralis minor nerve supply. (d) *, attachment fibres of the SM to the CP, Bp, brachial plexus; Sa, subclavian artery; Sv, subclavian vain

the clavicle (the SM appeared to be bicipital). In one specimen the muscular part of the SM extended directly to the body of the CP; in another there was an additional muscular attachment at the base of the CP; and in one an additional muscular extension inserting on to the glenohumeral joint capsule was observed. The SM was perforated in one male (right) specimen by a venous plexus, but no other anomalies of the subclavian vein were noted in this, or other, cases.

The anatomy of the distal attachment of the SM to the clavicle was invariant: there were no additional musculotendinous attachments. Conversely, the anatomy of the coracoid attachment fibres was highly variable. There were two specimens in which no coracoid attachment was noted on the right side, and one specimen in which no attachment was noted on the left side. Of the 49 of 52 specimens (94%) in which there was an extension of the SM as a fibrous structure passing from its inferolateral border to the coracoid this took one of three forms: a straight thick and strong cord-like band (18 specimens, 35%; Diagram 1; Figure 3a,e,f); a straight weak and thin cord-like structure (12 specimens, 23%; Diagram 2; Figure 3c); or a weak and thin planar twisted sheet-like structure (16 specimens, 31%; Diagram 3; Figure 3b,d) attached along the medial side of the base of the CP and extending to the body of the process, discrete from the clavipectoral fascia.

In two specimens (one right shoulder and one bilateral, 6%), the cord-like structure was duplicated with one band passing deeply to the base of the CP. The small fibrous extensions were often multiple, suggesting that these were a derivative form of a perforated planar sheet. In all cases, whatever their configuration, the fibrous structures were composed of shiny, parallel—oriented bundles of collagenous fibres, resembling an aponeurosis.

There was a clear gender difference in the form of the aponeurosis. In male specimens there were thick cord-like structures in 14/24 (58%) dissections with no side preference, and a twisted sheet form in 10/24 (42%) dissections with no side preference. In female specimens there were cord-like structures present in 9/28 (32%), and a twisted sheet structure in 5/28 (18%), without side preference. The remainder of the lateral aponeurotic extensions in both genders were of the small cord-like variety (Figure 3).

The results of measured observations are presented in Table 1. In summary:

1. The left clavicle tended to be longer in all cases for both genders, while the male clavicles were longer than female clavicles.
2. The shorter male right clavicles were slightly straighter than other clavicles, while the shorter female and longer male left clavicles were slightly more curved.
3. The mean length of the attachment of the SM into the sulcus M subclavii was relatively invariant, occupying, as a ratio of the clavicular length, approximately 38% (male)—41% (female) of the inferior surface of the clavicle. However, there was a wide range

FIGURE 3 The three forms of the aponeurotic expansion of the pars paramuscularis of the SMA. (a, e and f) are anterior views of the coraco-clavicular region of different left shoulders. Thick and strong cord-like distal attachments to the CP are observed, (b and d) show weak and thin planar twisted sheet-like distal attachments of the SM in anterior views of two right shoulders. In Picture (c), a weak and thin cord-like structure is seen in the anterior view of a left shoulder. (a, e, f) *: thick and strong cord-like structure, (b, d) *: weak and thin planar twisted sheet-like structure. (c) *: weak and thin cord-like structure. CC, coracoclavicular ligaments (conoideum and trapezoideum); SM, subclavius muscle

of actual lengths of the attachment into the sulcus, varying up to 4.5 cm in total length. The form of the aponeurotic extension (robust cord, small cord or twisted sheet) was not correlated with a particular range of lengths of the SM attachment into the clavicle.

4. The most lateral point of attachment of the SM was further from the muscular attachment the longer the clavicular attachment length, but there was no relationship with the form of the aponeurotic extension. This also held true for the coracoid attachment of the aponeurosis, when present.
5. The nerve to subclavius was observed and dissected in 44 of 52 specimens, while the artery was only seen in 19 of 52 dissections. The nerve entered the posterior aspect of the muscle at a mean distance of 4.7 cm (right) and 5.0 cm (left) from the lateral-most extent of the attachment in females, and 5.7 and 5.0 cm respectively in males, consistent with the longer clavicle of the males. The nerve entered the muscle belly at a mean of 50% of the length of the muscle (from its medial attachment) in the right specimens in females, and at a mean of 54% in the left specimens, while in the males the nerve entered the muscle at a mean of 59% of the muscle length on the right, and 54% on the left. While there were too few dissections in which the artery could be definitely identified, in those that it could be defined it entered the SM along with the nerve.

4 | DISCUSSION

The comparative evolutionary origin of the ventral thoracobrachial muscles from the ventral mesoderm anlage in relation to the ossification pattern of the coracoid primordium has been described (Stern, 2003). Ventral muscles closely related to the coracoid anlage (the equivalents of the human coracobrachialis and short head of the biceps muscles) functioned to depress the forelimb girdle and its extension (originally the fin of bony fish) while others functioned to stabilize the coracoid (and through it the dorsal structures: the

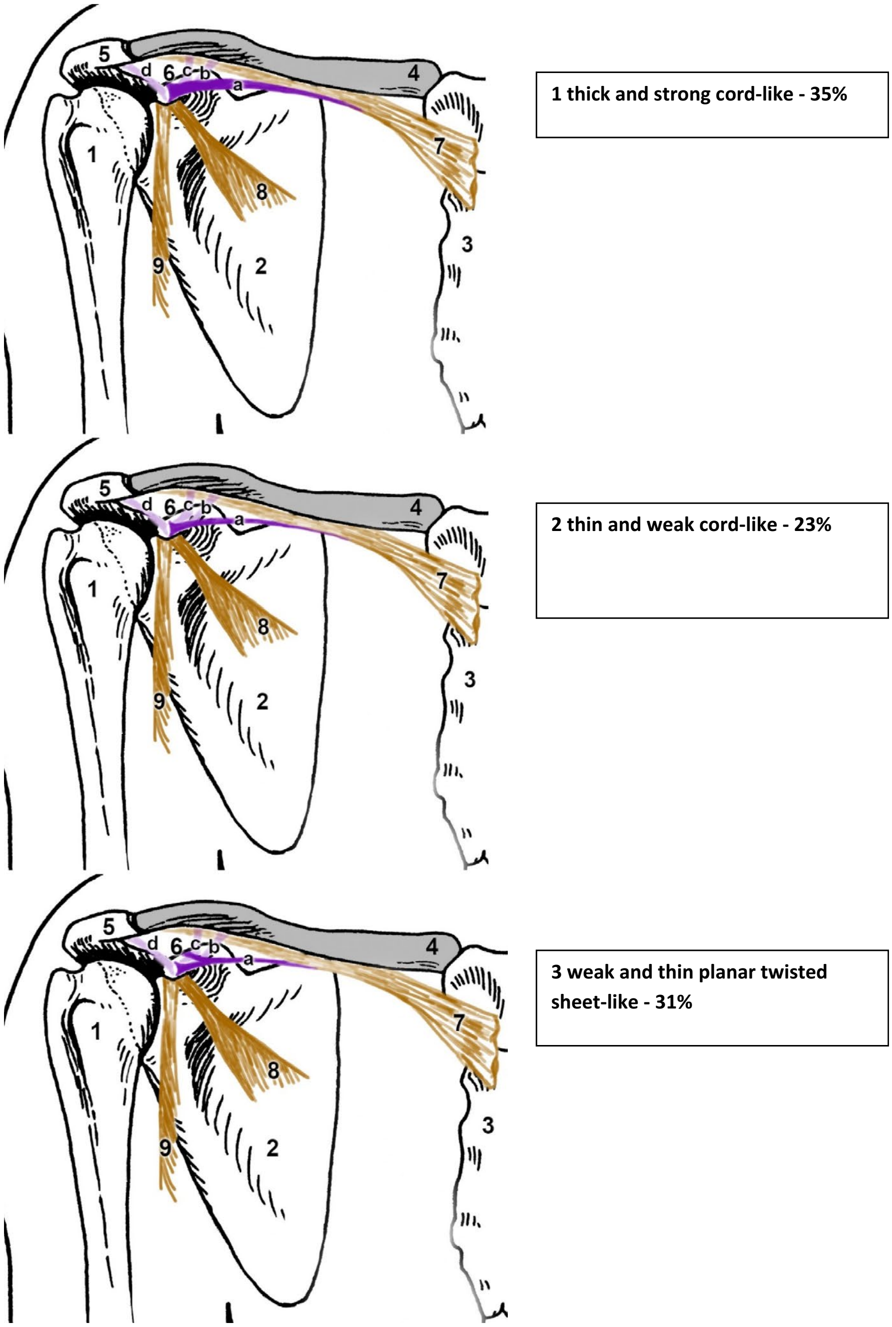

DIAGRAM 1 Diagram illustrates the relationship between the structures which attach and surround the CP in the different shapes as described in the text: diagram 1 thick and strong cord-like (35%), diagram 2 thin and weak cord-like (23%) and in diagram 3 weak and thin planar twisted sheet-like (31%). 1. Humerus, 2. Scapula, 3. Sternum, 4. Clavicula, 5. Acromion, 6. Coracoid Process, 7. Subclavius Muscle. a. Coracoid Attachement of the SM, b. Lig. Conoideum, c. Lig. Trapezoideum, d. Lig. Acromioclavicularis

scapula and scapulo-brachial muscles) through attachment to the thorax (pectoralis minor; Stern, 2003). While the SM is not referred to specifically in this account its attachments and course are closely related to the other ventral depressors of the forelimb girdle and an attachment to the coracoid is therefore not unexpected.

The anatomy of the human SM and its intrinsic tendon structure has been elucidated by Cave and Warwick Brown (Cave & Brown, 1952), who acknowledged the prior contribution of French anatomists to the description of the muscle and its relations. These authors described the muscle as taking attachment through a strong costal tendinous attachment (the pars libera) with a strong inferolateral tendinous border (the pars paramuscularis). The pars paramuscularis had a variable termination within or bordering the muscle and, most frequently, an additional tendinous slip in its lateral extent. In about 20% of cases the pars paramuscularis was described as terminating as a series of three fasciculi, of which the central band became intra-muscular. These authors considered the SM epimysium ('the subclavius sheath') as thickened laterally and contiguous with the

TABLE 1 Results of measurements and gender differentiation for clavicular length, proximal and distal attachment points of the SM, the length of the SM, and the entry point of the nerve to subclavius into the muscle. Measurements are in millimetres, and the methods of measurement are described in the text

	Female, *n* = 14			Male, *n* = 12		
		Range			Range	
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Clavicle length/cm						
1. Axial						
Right	14.7	12.5	15.5	16.1	15.5	17.5
Left	15.1	14	17	16.2	14.5	17.0
2. External						
Right	15.3	13	16	16.8	15.5	18.0
Left	15.6	15	17.5	17.0	15.0	18.0
Ratio of curvature (external/axial)						
Right	1.04	1.04	1.03	1.04	1.0	1.02
Left	1.03	1.07	1.03	1.05	1.03	1.06
Subclavius muscle length/cm						
1. Lateral extent of origin to lateral extent of clavicular distal insertion						
Right	9.3	7	11	9.7	9.0	11.0
Left	9.3	7.5	11	9.3	8.0	11.0
2. Lateral extent of origin to most medial coracoid insertion						
Right	8.8	7.5	10	9.3	8.0	10.5
Left	9.0	7.5	10	8.5	8.0	9.0
Length of clavicular insertion of subclavius/cm						
Right	6.3	5	8	6.4	5.5	8.0
Left	6.4	4	8.5	6.5	5.0	8.0
Distance from lateral extent of origin of subclavius to entry point of the nerve to subclavius/cm						
Right	4.7	3	6	5.7	5.5	6.0
Left	5.0	3	6.5	5.0	4.0	5.5

coraco-clavicular ligament: they recognized curvilinear bundles of fibres running perpendicular to the direction of the main muscle fibres and converging on the CP. The authors described these fibres as forming the upper part of the 'costo-coracoid membrane' which, when well-developed were synonymous with the "medial coraco-clavicular ligament of the French anatomists" (Cave & Brown, 1952). We believe this corresponds to the structure we define here as the aponeurosis of extension of the SM fascia in its various forms, but discrete from the clavipectoral fascia. Testut (Cave & Brown, 1952) illustrated the anatomy of the SM in relation to the 'clavi-coraco-axillary aponeurosis'. The coracoid tip is held within the aponeurosis, suspended from the clavicle, and guided by the muscles enveloped by the clavipectoral fascia (the SM, the pectoralis minor, and the coracobrachialis and short biceps brachii). The SM and its lateral aponeurotic extension thereby contributes to a 'functional system' which controls the position of the scapula in relation to the thorax.

We found the aponeurotic extension to be more common than previously documented (Mori, 1964). If only the strong cord-like lateral fibrous extension is considered, then the frequency of this form in our series remains greater (35%) than in other series (Mori, 1964). We consider the twisted planar sheet-like aponeurosis, present in 31% of specimens, a variant (possibly an archetype) of this lateral extension, and not simply a fascial septum from the clavipectoral fascia. It is unclear why there should be a gender difference in the form of the lateral extension, since we were not able to determine what the former occupations of the donors had been, assuming that anatomical variation reflects functional demands. The form of the SM has not been documented in immature specimens. It is therefore not clear whether the lateral extension is always initially present as a planar sheet-like form to which functional forces are applied, generating adaptive changes in the structure over time. It is assumed that ancestrally both genders would have an equal need for regulation of upper extremity function in the arboreal environment, so there is no reason to suspect that development of male and female SM anatomy should be embryologically discrete.

The strong cord-like form described here would appear to be an extension of the pars paramuscularis forming a strong, concave inferior border to the musculo-aponeurotic structure. Importantly, this structure bridges three joints (the sternoclavicular, SCJ, scapulo (acromio-) clavicular, ACJ and the first sternocostal joint). The tendinous border is relatively inelastic, although deformable. This suggests that the SM might actually function to pretension the aponeurosis and pars paramuscularis, contributing to the control of the motion of the distal clavicle as an antagonist of the primary scapular motion muscles. In this connection it may be pertinent to note that the nerve supply to the serratus anterior (the only other muscle in the shoulder girdle with a unique nerve supply) is also derived from axons from the 5th and 6th cervical segments via the upper trunk of the brachial plexus. The observation that the nerve to subclavius (1–5,7) inserts into the muscle approximately half-way along its length further supports the concept that the muscle contracts concentrically (i.e. a bipolar motion towards the central neuromuscular attachment), more as a fusiform muscle, rather than as a delta-shaped or multipennate muscle. Contraction of the muscle cannot shorten the distance between the SCJ and ACJ (since the length of the clavicle dictates this distance) so the effect of contraction must be primarily to increase the tension in the tendinous border of the muscle and the aponeurosis.

While the function of the SM in humans has been assumed to be that of stabilizing the SCJ (1, 3, 5, 7, 16), evidence from studies of the comparative anatomy (18) and functional electrophysiology of the SM in arboreal Old World monkeys (17) suggests that the SM functions to regulate the output of kinetic energy in movement of the upper extremity rather than as a primary stabilizer of the SCJ or ACJ. That the nerve to subclavius serves no other muscle suggests that the SM has, or had, an important role in efficient brachiation, the modern equivalent motion being of overhead sport-related activities. Extending the muscle through a strong aponeurosis to the coracoid (and so the scapula) would enhance this function.

We have shown that the anatomy of the lateral aponeurotic extension of the SM, previously termed the 'medial coraco-clavicular ligament' is variable, but that the presence of structures which may contribute to the system of control of scapular motion is more common than previously documented. We determined that these structures, which occur in three basic forms, are discrete from, but intimately related to, the clavipectoral fascia. The anatomy of the nerve supply to the muscle suggests that the muscle acts primarily on its own tendinous components rather than on the clavicle itself, using the clavicle attachment as the base from which effective muscle action can occur to contribute to the mechanism of the 'clavi-coraco-axillary aponeurosis'.

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