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HUMAN ANATOMY

Anatomical study of myofascial continuity in the anterior region of the upper limb

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Sequences

Summary Fifteen unembalmed cadavers were dissected in order to study the "anatomical continuity" between the various muscles involved in the movement of flexion of the upper limb. This study demonstrated the existence of specific myofascial expansions, with a nearly constant pattern, which originate from the flexor muscles and extend to the overlying fascia. The clavicular part of the pectoralis major sends a myofascial expansion, with a mean length of 3.6 cm, to the anterior region of the brachial fascia, and the costal part sends one to the medial region of the brachial fascia (mean length: 6.8 cm). The biceps brachii presents two expansions: the lacertus fibrosus, oriented medially, with a mean height of 4.7 cm and a base of 1.9 cm, and a second, less evident, longitudinal expansion (mean length: 4.5 cm, mean width: 0.7 cm). Lastly, the palmaris longus sends an expansion to the fascia overlying the thenar muscles (mean length: 1.6 cm, mean width: 0.5 cm).

During flexion, as these muscles contract, the anterior portion of the brachial and antebrachial fascia is subject to tension. As the fascia is rich in proprioceptive nerve endings, it is hypothesized that this tension activates a specific pattern of receptors, contributing to perception of motor direction. If the muscular fascia is in a non-physiological state, these mechanisms are altered, and the proprioceptors in the fascia may be incorrectly activated, thus giving rise to many types of extra-articular pain.

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Introduction

It has been known since antiquity that many types of extra-articular pains, typical of myofascial pain syndromes, may move from one segment to another. In fact, the term "rheumatism" means "a flux" (Stedman, 1995). Attempts to manage this phenomenon clinically have employed a variety of physical modalities deriving from different theoretical perspectives (Bossy et al., 1980; Travell and Simons, 1983; Busquet, 1995; Myers, 2001; Stecco, 2004; Schleip et al., 2006). Possibly the most ancient theory is that of acupuncture, with its meridian lines distributed according to precise areas, never physically demonstrated (Lebarbier, 1980).

More recently, Langevin and Yandow (2002), Ahn et al. (2005) and Langevin (2006) have hypothesized that acupuncture meridians coincide with inter- and intra-muscular connective tissue planes, and demonstrated that rotation of the acupuncture needle causes "whorling" of the subcutaneous tissue (Langevin et al., 2001), extensive fibroblast spreading and formation of lamellipodia (Langevin et al., 2006).

The French school has hypothesized the existence of a functional connection between muscular groups with the same motor action, coining the term "*chaînes musculaires*" (Souchard, 1993; Busquet, 1995). In anatomy textbooks (e.g. Benninghoff and Goerttler, 1978), some functional correlations among muscles are also described. In recent years, some authors have hypothesized that these connections are not only functional, but also that the deep muscular fascia is the element of connection among the various muscle groups. Maas et al. (2005), Yucesoy et al. (2006), Meijer et al. (2006) and Rijkelijkhuizen et al. (2007) agree that extra-muscular myofascial force transmission occurs between adjacent synergistic and antagonist muscles, as well as between distant muscles.

Myers (2001) and Stecco (1988, 1996, 2004) describe models explaining, respectively, myofascial trains and sequences comprising myofascial connections crossing the entire body, linking the head to the toes and the centre to the periphery. Both the authors postulate that these trains, or sequences, are directly involved in the organization of movement as well as muscular force transmission. However, well-documented myofascial trigger points (Travell and Simons, 1983) do indicate the existence of a connection between the location of pain and its origin, often quite a distance away, thereby confirming the concept of continuity between different segments.

As in this work, we considered the anterior region of the upper limb; we initially evaluated how these models correlate with the various anatomical segments of the arm.

The acupuncture model describes three yin meridians (Fig. 1A) in the anterior region of the upper limb: those of the lung, the pericardium and the heart. The lung meridian begins below the clavicle, medial to the caudal border of the coracoid process and, maintaining a lateral position, continues along the flexor region of the arm and forearm, to terminate in the thumb. The pericardium meridian begins laterally to the nipple, passes along the anterior axillary fold, and extends along the midline of the anterior region of the limb, to finish in the middle finger of the hand. The heart meridian begins in the axilla, extends down the medial side of the arm and forearm, to finish in the last phalanx of the little finger (Manuale Teorico-pratico di Agopuntura, 1978; Hecker et al., 2001). These three acupuncture meridians represent lines of connection between different acupuncture points, whose location is defined by precise distances known as "*cun*". Apart from the studies mentioned above, which suggest a correlation with loose connective tissue planes (Ahn et al., 2005), there is no documented correspondence to any specific, underlying anatomical structures.

The Anatomy Trains model (Myers, 2001) distinguishes two myofascial trains in the anterior region of the upper limb: one deep and one superficial (Fig. 1B and C), formed of both muscular and fascial components. In particular, the deep frontal line begins with the pectoralis minor, continues with the short head of the biceps brachii and the coracobrachialis, joins two fibrous components, the radius periosteum and the radial collateral ligament, and ends with the thenar muscles. The pectoralis major, the anterior portion of the latissimus dorsi and the teres major form the superficial frontal line of the arm proximally. They are all inserted into the medial intermuscular septum and, at the epicondyle, this line proceeds along the flexor digitorum superficialis to the palm of the hand.

The Fascial Manipulation model (Stecco, 2004), distinguishes a total of six sequences in the upper limb, arranged according to the three spatial planes. Muscle components, particularly those fibres that are inserted into overlying fasciae and septa, form these sequences together with fascial components. In the anterior portion of the upper limb, three sequences, the antemotion, mediomotion and intra-rotation sequences, are described. The antemotion sequence (Fig. 1D) begins in the thumb with the muscles and fascia of the thenar eminence, and continues, via the flexor retinaculum, along the anterior antebrachial fascia with the underlying flexor carpi radialis. At the elbow, the

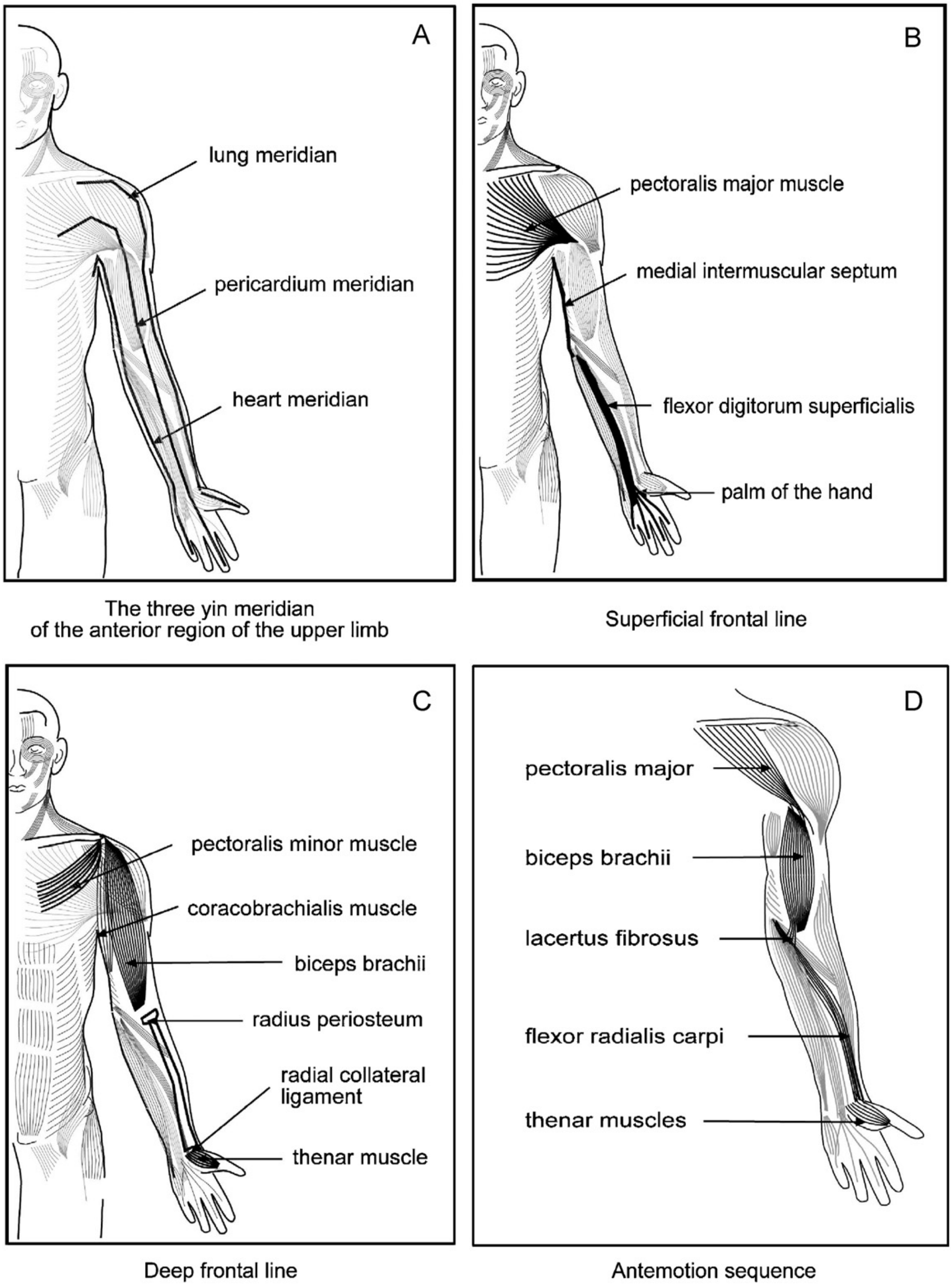

Figure 1 (A) Diagram of the distribution in the upper limb of the three yin meridians. (B) The superficial frontal lines of Myers. (C) The deep frontal line of Myers. (D) The antemotion sequence according to Fascial Manipulation of Stecco.

lacertus fibrosus provides the continuity between the antebrachial and brachial fasciae, with the related biceps brachii. Proximally, the brachial fascia continues into that of the pectoralis major. The intra-rotation sequence begins with the lumbricals, which are inserted into the tendons of the flexor digitorum profundus. The sequence continues in a proximal direction with the pronator teres, medial intermuscular septa, and subscapularis. The mediomotion sequence is defined by the hypothenar muscles, flexor ulnaris carpi muscle, medial intermuscular septum, and coracobrachialis.

According to the *chaînes musculaires* model, the coracobrachialis, biceps, brachialis, supinator teres, all the flexor muscles of the forearm and, lastly, the thenar and hypothenar muscles (Nava, 2006; Souchard, 1993; Busquet, 1995) form the anterior chain of the arm.

It is evident that the lung meridian, the anterior chain of the arm, the deep frontal line of the arm, and the sequence of antemotion all overlap from a topographical point of view (Langevin and Yandow, 2002; Ahn et al., 2005; Langevin, 2006). By means of dissection, we wished to ascertain the existence of definite myofascial connections along these projections in order to give these "lines" an anatomical basis.

Materials and methods

Fifteen cadavers (11 men, 4 women, mean age 84.4 years), neither embalmed nor frozen previously, were analysed (Table 1). With the cadaver in the supine position, dissections consisted of an analysis of the anterior region of the shoulder and upper limb. Direct visual observations and photographs (Canon EOS 350 digital camera) were taken without magnification. After removing the skin and subcutaneous fat, the muscular fasciae and their structure were examined. Particular attention was paid to the direction of the collagen fibre bundles, the relationship of every muscle with its fascia, and the presence of any muscle fibres inserted directly into the overlying fascia. Similarly, the presence of any myofascial expansions (considered as fibrous extensions originating from the muscle and continuing beyond the muscle itself) into the brachial and antebrachial fascia were also noted, with particular attention to their spatial relationships. All these expansions were photographed and subsequently catalogued. Simple manual traction was applied, via forceps, to the belly of the muscles along the direction of their fibre bundles in order to reproduce the traction that myofascial expansions exert on the fascia. This allowed visual evaluation of the direction of the resulting lines of force. In every phase of dissection, visual observations and photographs were made with the limb in the anatomical position along the trunk. Subsequently, some passive movements were performed to identify possible variations in the lines of force on the brachial and antebrachial fascia. The resistance to traction of the expansions was evaluated in 11 specimens out of 15. Two SK dynamometers (Japan) were used: one with sensitivity from 5 g to 5 kg, and one from 100 g to 25 kg. These instruments were attached to the distal extremity of the myofascial expansions, previously detached from the fascia, while the proximal insertion was maintained. Non-absorbable nylon sutures (Ethilon 2-0) were used to attach the expansions to the dynamometer (Fig. 2). Then, manual traction along the long axis of the muscles was applied to calculate the resistance to traction of these fibres to the point of rupture.

Table 1 Subjects examined.

Subject	Age (year)	Gender
1	87	F
2	84	M
3	80	M
4	86	M
5	92	M
6	75	M
7	93	M
8	84	F
9	62	M
10	90	M
11	89	F
12	86	M
13	85	M
14	79	F
15	94	M
Mean age	84.4	11 M 4 F

Results

In all specimens, the deep fascia of the upper limb formed a sheath, which covered all the arm muscles. Proximally, it was continuous with the axillary fascia, pectoralis fascia and deltoid fascia, and distally with the palmar fascia. During dissection, the brachial fascia was always easily separable from the biceps brachii, being only attached to the lateral and medial intermuscular septa and to the lateral and medial epicondyles. Instead, the fasciae of the pectoralis major and deltoid adhered firmly to their respective muscles, due to a series of intra-muscular septa, which branched off from the internal surface of the same fasciae. This study verified that the pectoralis major, biceps brachii and palmaris longus muscles insert expansions into the brachial and antebrachial fascia, and that they are always present and followed a constant pattern (Table 2). Differences between right and left were not found during this study ($P > 0.05$).

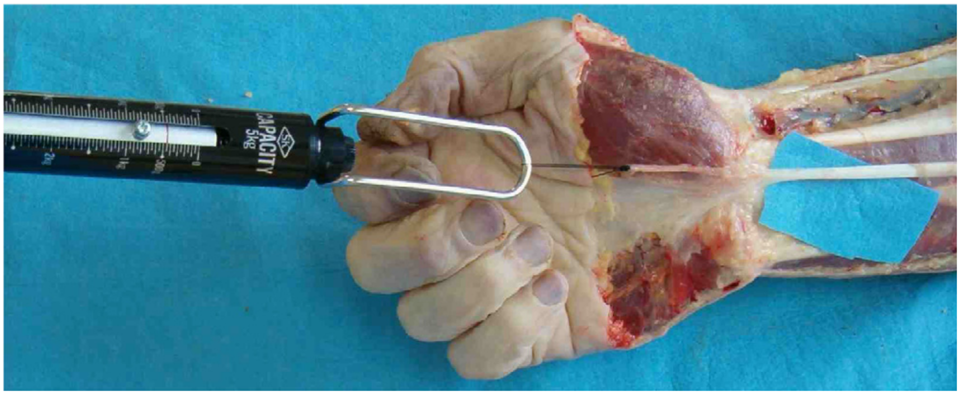

Figure 2 Resistance to traction of palmaris longus expansion to fascia of thenar eminence. A dynamometer with sensitivity from 5 g to 5 kg was attached to the distal extremity of this expansion, previously detached from the fascia; the proximal insertion was maintained. Traction along the mean axis of the palmaris longus was applied to the point of rupture of the myofascial expansion (see Table 3).

The pectoral fascia continued laterally with the brachial fascia, extending two myofascial expansions to it (Fig. 3). The clavicular part of the pectoralis major sent an expansion to the anterior region of the brachial fascia. It had a rectilinear course along the axis of the limb, with a mean length ($\pm$SD) of 3.61 ($\pm$1.61) cm. The costal part sent an expansion to the axillary fascia and then to the medial region of the brachial fascia, with a mean length ($\pm$SD) of 6.83 ($\pm$2.78) cm. Only in one subject (a mastectomized female), it was not possible to evaluate this insertion because the pectoralis major and pectoral minor had been removed surgically. Manual traction via forceps, applied to the clavicular part of the pectoralis major muscle, produced lines of force that spread along the anterior part of the brachial fascia; conversely, traction applied to the costal part of the pectoralis major muscle produced lines of force that propagated towards the axilla and the medial region of the brachial fascia.

The biceps brachii has an expansion to the deep fascia of the forearm: the lacertus fibrosus or bicipital aponeurosis. This originated from the biceps tendon, distal to its musculotendinous juncture, and it was inserted into the proximal portion of the antebrachial fascia (Fig. 4). It was composed of two groups of collagen fibres arranged in various directions. The main group was oriented in an oblique direction, downwards and medially, and then merged with the forearm fascia. It was fan-shaped and had a mean height ($\pm$SD) of 4.77 ($\pm$1.09) cm and a base ($\pm$SD) of 1.97 ($\pm$0.71) cm. When this portion of the fascia was detached from the underlying muscles, it was evident that it gave origin to numerous muscular fibres and intermuscular septa. The second bundle of collagen fibres of the lacertus fibrosus, although less evident, was arranged longitudinally, parallel to the median line of the forearm, and had a mean length ($\pm$SD) of 4.52 ($\pm$1.09) cm and a mean width ($\pm$SD) of 0.72 ($\pm$0.23) cm. This expansion was initially free to slide over the main biceps tendon, and then extended between the flexor carpi radialis and brachioradialis; numerous fibres of these same muscles originated from it. When traction was applied via forceps to the biceps tendon proximal to the bicipital aponeurosis to simulate muscular traction, two lines of force appeared: one in a median direction, corresponding to the arciform fibres, and one in a longitudinal direction, along the central part of the forearm.

At the wrist, many collagen fibre bundles forming the flexor retinaculum reinforced the antebrachial fascia. Distally, the latter continued with the palmar fascia which, in turn, was reinforced by the aponeurosis of the palmaris longus. The palmaris longus sent some myofascial expansions to the flexor retinaculum and to the fascia overlying the thenar muscles (Fig. 5). The expansion to the thenaris fascia had a triangular form, with a mean height ($\pm$SD) of 1.63 ($\pm$0.21) cm and a base ($\pm$SD) of 0.52 ($\pm$0.19) cm. Similarly, some muscular fibres of the flexor pollicis brevis and palmaris brevis were inserted directly into the aponeurosis of the palmaris longus. When manual traction was applied in a proximal direction to the palmaris longus tendon, simulating the contraction of this muscle, lines of force appeared in both the palmar and thenar fasciae. In only two subjects was the palmaris longus absent.

Table 3 lists the mean strength necessary to lacerate the expansions. The lacertus fibrosus was the most resistant, sustaining average traction of

Table 2 Myofascial expansions to anterior region of deep fascia of upper limb.

Subject	Side	Pectoralis major		Biceps (lacertus fibrosus)				Palmaris longus (expansion to thenaris fascia)	
		Clavicular part	Costal part	Main part		Longitudinal part			
		Length	Length	Length	Width	Length	Width	Length	Width
1	dx	5.0	7.0	4.5	1.5	5.5	0.5	–*	–*
	sn	4.0	3.0	5.5	2.0	4.0	0.4	–*	–*
2	dx	–*	–*	5.3	1.8	6.5	0.6	1.6	0.5
	sn	7.5	12.5	3.8	1.7	6.5	1.1	1.7	0.6
3	dx	6.0	5.0	7.2	2.5	4.5	0.6	1.6	0.6
	sn	4.0	6.0	6.5	3.0	4.0	0.6	1.5	0.7
4	dx	3.0	6.0	4.5	2.0	3.5	0.4	1.8	0.4
	sn	5.0	6.0	4.2	0.8	4.0	0.6	1.7	0.3
5	dx	2.0	8.0	5.2	1.4	4.5	0.8	–*	–*
	sn	3.0	8.0	4.8	1.4	7.0	1.2	–*	–*
6	dx	1.0	14	4.2	2.0	5.0	0.5	1.9	0.2
	sn	1.0	8.0	5.8	3.0	3.5	0.7	1.7	0.6
7	dx	4.0	3.5	7.2	4.0	4.5	0.7	1.6	0.7
	sn	4.5	7.0	6.0	2.2	5.0	0.8	1.7	0.5
8	dx	1.0	6.0	3.2	1.5	4.0	0.6	2.1	0.8
	sn	2.0	5.0	4.4	0.9	3.5	0.5	1.2	0.8
9	dx	5.5	3.0	6.2	2.0	7.0	0.8	1.6	0.4
	sn	2.5	3.0	4.5	2.0	4.0	0.7	1.7	0.6
10	dx	4.0	5.5	4.8	2.4	3.5	0.9	1.5	0.3
	sn	6.0	10	5.5	3.0	4.5	1.2	1.3	0.7
11	dx	5.5	5.0	4.2	1.9	3.5	0.5	1.5	0.2
	sn	3.0	5.0	4.7	1.0	5.5	0.7	1.4	0.6
12	dx	3.0	7.0	2.8	1.1	4.5	0.8	1.5	0.4
	sn	3.5	10	4.2	2.2	5.2	1.2	1.6	0.7
13	dx	4.0	7.0	3.7	1.5	4.2	0.6	1.4	0.6
	sn	2.0	5.0	4.3	1.8	3.5	0.8	1.9	0.5
14	dx	3.0	12	4.5	1.5	3.5	0.6	1.6	0.2
	sn	3.5	5.0	4.0	2.0	3.2	1.0	2.0	0.3
15	dx	4.0	7.0	3.2	2.7	4.4	0.7	1.6	0.5
	sn	2.0	8.5	4.5	2.5	3.5	0.5	1.7	0.8
		Mean value (±SD): 3.61 (±1.61)	Mean value (±SD): 6.83 (±2.78)	Mean length (±SD): 4.75 (±2.25), mean width (±SD): 1.97 (±0.9)		Mean length (±SD): 4.77 (±1.09), mean width (±SD): 0.72 (±0.23)		Mean length (±SD): 1.63 (±0.21), mean width (±SD): 0.52 (±0.19)	

Where expansions were found, measurements are reported in cm.
*Impossibility of evaluating fascial insertion, due to absence of muscle.

Figure 3 Expansions of pectoralis major muscle to brachial fascia.

5.63 kg; the expansions of the palmaris longus were weaker, sustaining traction of about 2.5 kg. Intermediary values were obtained for the pectoralis major expansions (about 4 kg).

Discussion

This study demonstrates the existence of an anatomical continuity between all the muscles of the flexor region of the upper limb. Connections were found in all subjects and, above all, they had a constant anatomical structure. This finding contrasts that of other authors (Chiarugi, 1904; Yazar et al., 1998) who considered these expansions to be simple anatomical variations. The myofascial connections create an anatomical continuity between different muscles involved in the same directional movement, and confirm the anatomical basis of the *chaînes musculaires*, sequences, and myofascial trains. The expansions allow reciprocal feedback between fascia and muscles: the fascia can perceive tension produced by a muscle due to its expansions, and can transmit it to a distance, informing the distal muscle about the state of contraction of the proximal muscle, possibly via muscle spindles activation. It is hypothesized that when muscles contract to actuate a movement, they simultaneously stretch the same fascia into which they extend expansions. For example, during the movement of antemotion of the shoulder, contraction of the clavicular fibres of the pectoralis major produces stretching in the anterior region of the brachial fascia. Likewise, during flexion of the elbow, contraction of the biceps stretches the anterior region of the antebrachial fascia by virtue of its bicipital aponeurosis and, during flexion of the wrist, contraction of the palmaris longus pulls on the flexor retinaculum, palmar aponeurosis and thenar fascia. In addition, manual traction applied to the muscle bellies produces lines of force within the muscular fascia that mirror the same direction of the stretched muscular fibres. This forms an effective anatomical continuity between the various muscular components involved in flexion of the upper limb. Marshall (2001), reviewing the deep fascia of the upper limb, states, "all these fascial attachments provide an excellent illustration of how the thickness and strength of aponeuroses and fasciae precisely mirror the forces generated by muscular action".

It is also well known that the muscular fascia is innervated, mostly by proprioceptive nerves (Stilwell, 1957; Yahia et al., 1992; Staubersand and Li, 1996; Stecco et al., 2006). However, very little is known about the fascia as a sensory, target organ, or how the central nervous system codifies and integrates spatial afferents from it (Langevin and Sherman, 2007). These mechanoreceptor nerves, which are immersed in a fibrous stroma, are sensitive to tension. When a muscle contracts, the points of its bony insertions permit mechanical actions, whereas expansions to the fascia stretch specific zones of that fascia. We hypothesize that fascia stretching activates specific patterns of

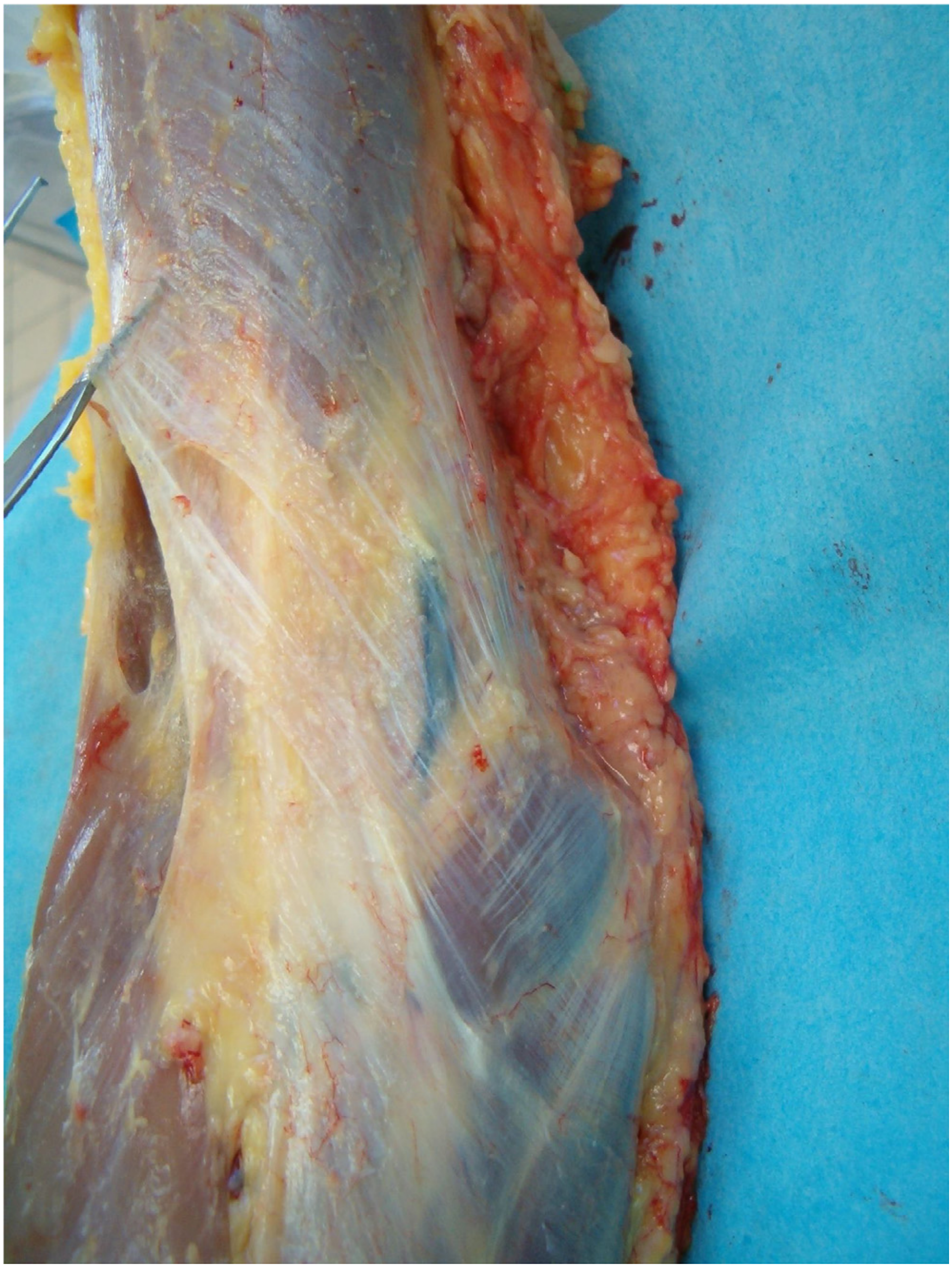

Figure 4 Expansion of biceps brachii muscle (lacertus fibrosus) to antebrachial fascia.

proprioceptors, resulting in perception of motor direction.

Lastly, it is known that the formation and maintenance of collagen in dense connective tissue is highly dependent on stress and physical stimuli, and that it may be altered in pathological conditions (e.g. immobilization, trauma, overuse syndrome, surgery) (Langevin et al., 2006; Langevin and Sherman, 2007; Hammer, 2007a, b). In the absence of normal physiological elasticity, the receptors embedded within the fascia may be in an active state even at rest. Consequently, any further stretching, produced by muscular contraction and transmitted to the fascia by myofascial expansions, may cause over-maximal input. It is also known that all receptors, over a certain threshold, can potentially become algoceptors with consequent propagation of nociceptive signals even in situations of normal physiological stretch (Baldissera, 1996). This may also contribute to the origin of numerous myofascial pain syndromes.

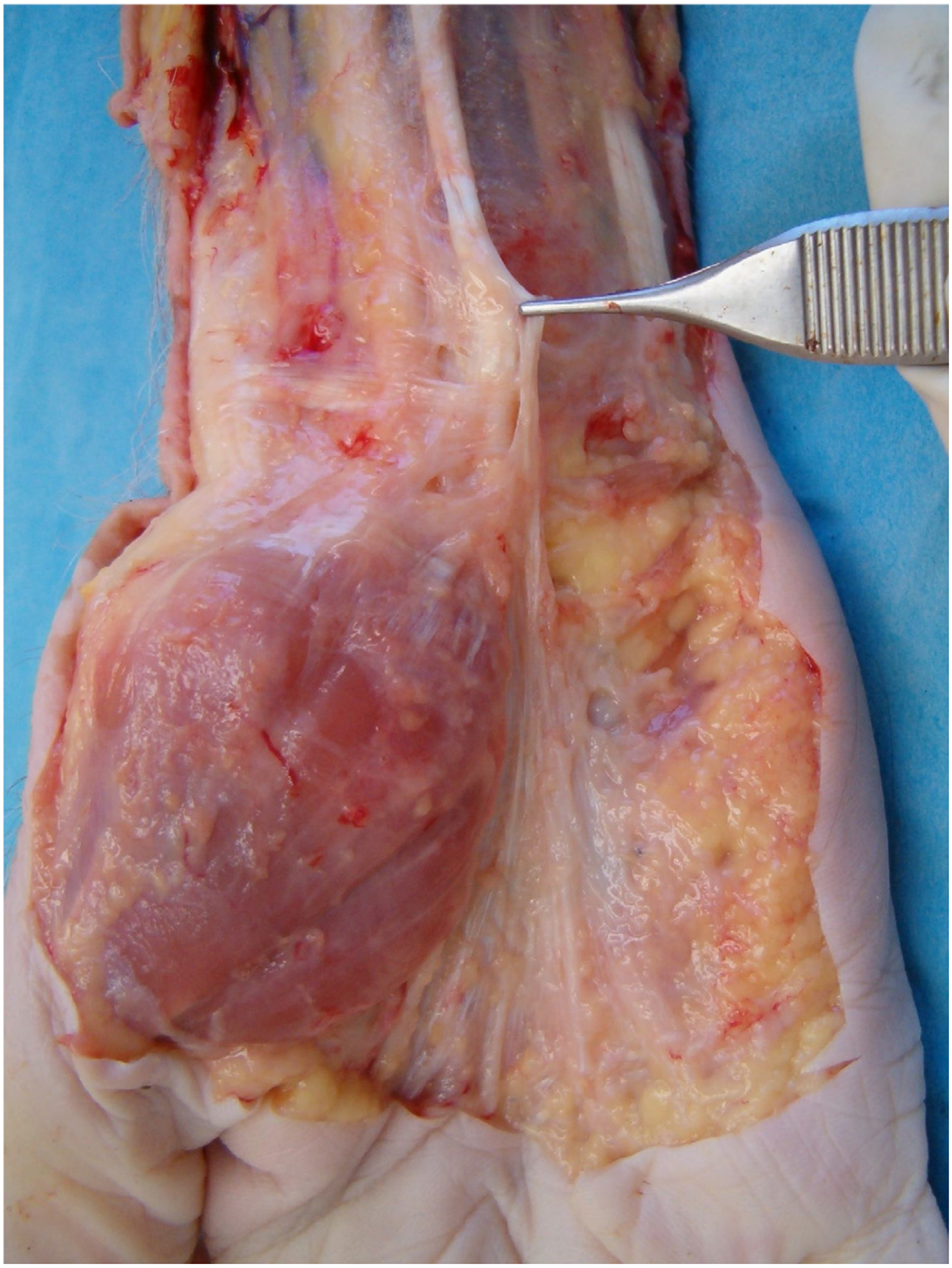

Figure 5 Expansion of palmaris longus muscle to fascia of thenaris eminence.

Table 3 Resistance to traction prior to rupture of expansions in 11 subjects, expressed in kg.

	Subjects											
	1	2	3	4	5	6	7	8	9	10	11	MV
Pectoralis major	5	3.5	3.5	4.5	2.5	2.5	4.8	3	4.5	5.5	4	3.9
Biceps	6.5	7	8.5	6	3	6	4.5	6.5	5	5.5	3.5	5.6
Palmaris longus	2	1.5	2.5	1.5	1.5	2	2	2	3	3	1.5	2.1

Last column: mean values (MV).

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