REVIEW

Myofascial Chains of the Upper Limb: A Systematic Review of Anatomical Studies

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The presence of structural in-series continuity between skeletal muscles has been confirmed in the trunk and lower extremity. However, it is not yet clear whether the same architecture can be found in the upper limb. Therefore, the aim of the present study was to review the available literature considering the existence of myofascial chains in the shoulder-arm region. Two independent investigators performed a systematic literature search using MEDLINE (PubMed) and Google Scholar (each 1900–2019). Peer-reviewed anatomical dissection studies reporting myofascial in-series continuity in the upper extremity were included. The methodological quality of the included studies was assessed by the QUACS scale. Thirteen studies were included in the review. Analysis of these papers led to the identification of three myofascial chains: the ventral arm chain (pectoralis major, brachial fascia/biceps brachii, flexor carpi ulnaris/brachioradialis/supinator, based on five studies); the lateral arm chain (trapezius, deltoideus, lateral intermuscular septum/brachialis, brachioradialis, four studies); and the dorsal arm chain (latissiumus dorsi/teres minor/infraspinatus, triceps brachii, anconeus, extensor carpi ulnaris, six studies). There is good evidence for direct serial tissue continuity extending from the neck and shoulder region to the forearm. Despite this intriguing finding, which could have implications for health professionals and the treatment of musculoskeletal disorders, further research is needed to establish the mechanical relevance of the identified myofascial chains. Clin. Anat. 00:000–000, 2019.

Key words: continuity; fascia; force transmission; muscles; cadavers; connective tissue

INTRODUCTION

Most popular descriptions of human anatomy present the skeletal muscles as structurally independent actuators with distinct origins and insertions. However, recent research has challenged this perspective, instead suggesting ubiquitous structural continuity between muscular and collagenous connective tissue. On a micro-level, muscle fibers merge tightly with their endomysium over the full peripheral length (Yucesoy, 2010). When the muscle is considered from a more macroscopic perspective, a similar construction becomes evident as the muscle is intimately fused with the surrounding fascia (Wilke et al., 2018).

Myofascial continuity is not limited to a muscle and its associated connective tissue. In a systematic review analyzing data from 62 cadaver studies, Wilke et al. (2015) addressed the question whether neighboring muscles are also coupled morphologically. In fact, there is strong evidence of continuity in most of the cases examined. For instance, on the dorsal side of the body, different types of soft tissue provide a continuous pathway from the toes of the feet to the occipital bone. Caudally, fibers of the plantar aponeurosis fuse with the Achilles tendon, which in turn gives origin to the gastrocnemius and its fascia (Snow et al., 1995; Stecco et al.,

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2013). At the knee joint, a fascial band links the calf muscles to the hamstrings (Tuncay et al., 2007), which in turn attach to the lumbar fascia/the erector spinae muscle via the sacrotuberous ligament (Vleeming et al., 1995). This and other body-wide tissue planes (e.g., on the lateral side) have been dubbed "myofascial chains."

In contrast to the tissue continuity between muscles located parallel to each other (e.g., tibialis anterior and extensor digitorum longus), which has also been verified (Yucesoy, 2010), it is a hallmark of myofascial chains that their components are arranged according to the direction of the muscle fibers and the lines of pull. This in-series organization is important because it can transfer greater force. Experimental research on cadavers and in vivo studies support this hypothesis. Considerable mutual interactions between the constituents of myofascial chains have been demonstrated (e.g., by Vleeming et al., 1995), which is why some authors assume they are implicated in musculoskeletal disorders (Wilke et al., 2018).

Although the existence of myofascial chains and their mechanical relevance have been investigated in the lower limb and the trunk (Krause et al., 2016), there has been little research regarding the upper extremity. The objective of the present study was therefore to identify morphologically linked muscle-fascia pathways in the shoulder-arm region based on a review of published anatomical dissection studies.

MATERIALS AND METHODS

This systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Moher et al., 2009). Two independent investigators researched the literature systematically to identify peer-reviewed anatomical cadaver studies (publication between 1900 and 2019) that reported morphological in-series tissue continuity between muscles of the upper limb and shoulder. The following were excluded: studies examining or describing continuity between muscles located parallel to each other, animal studies, and case reports. The same applied to articles in languages other than German or English.

Relevant publications were identified using Google Scholar and MEDLINE (PubMed; searched with MeSH terms). The search strategy for Google Scholar was adapted from previous systematic reviews (Wilke et al., 2016, 2019) and included different operators alongside the names of the supposedly connected muscles/structures. The exact term (tissues named are an example) was: "(cadavers OR dissection) AND ('intermuscular septum' AND 'pectoralis major') AND (continuity OR expansion OR extension OR fuses OR merges OR blends)." For each search, the first 200 hits returned were examined for eligibility. A similar search was conducted in the PubMed database to complement the findings of the foregoing procedure. The reference lists of all detected studies were also checked.

Data were extracted by two independent investigators, and a continuity was only documented if both agreed that it had been clearly reported. The methodological quality of the included studies was assessed using the QUACS scale (Quality Appraisal of Cadaveric Studies), which has been shown to be a reliable and valid tool in the quality assessment of observational cadaveric studies (Wilke et al., 2015). The instrument is a checklist of 13 dichotomous items, each rated either zero (no/not stated) or one (yes/clearly present). The quality score is calculated in percentage: 0%–20% indicates poor, 21%–40% fair, 41%–60% moderate, 61%–80% substantial, and 81%–100% excellent. Two investigators measured the quality independently. In the event of disagreement, a third reviewer cast the deciding vote.

RESULTS

A flow diagram of the literature search is shown in Figure 1. A total of 3,024 records were found using the algorithms described. After the exclusion criteria were applied, 13 were considered eligible and described serial tissue continuity in the arm and shoulder region. Study quality (Table 1) as assessed by the QUACS scale was substantial with an average score of 69% $\pm$ 14% (range: 42%–92%). Three myofascial chains could be identified (Table 2).

Ventral Arm Chain

The ventral arm chain takes origin at the pectoralis major muscle. It is intimately fused with the brachial fascia, which has a linkage to the biceps brachii. At its distal part, the ventral arm chain fans out bilaterally as the bicipital aponeurosis (lacertus fibrosus) and is continuous with both the brachioradialis and the flexor carpi radialis muscle.

Lateral Arm Chain

The lateral arm chain begins in the neck. The fascia of the trapezius muscle fuses directly with the middle deltoid. From here, continuity with the lateral intermuscular septum of the arm provides the morphological connection to the lower arm, namely the brachioradialis and the extensor carpi radialis brevis.

Dorsal Arm Chain

Two pathways start on the back of the shoulder and arm: Both the latissimus dorsi and the infraspinatus and teres minor muscles fuse with the triceps brachii. At the elbow, the latter merges with the small anconeus muscle, which then connects to the extensor carpi ulnaris of the lower arm.

DISCUSSION

The findings of the present review suggest the existence of three myofascial chains in the shoulder-arm region. To the best of our knowledge, our analysis of the literature is the first to summarize the available evidence regarding this question systematically. Previously, there have been popularized descriptions of myofascial chain concepts (Busquet, 1992; Denys-Struyf, 1995; Myers,

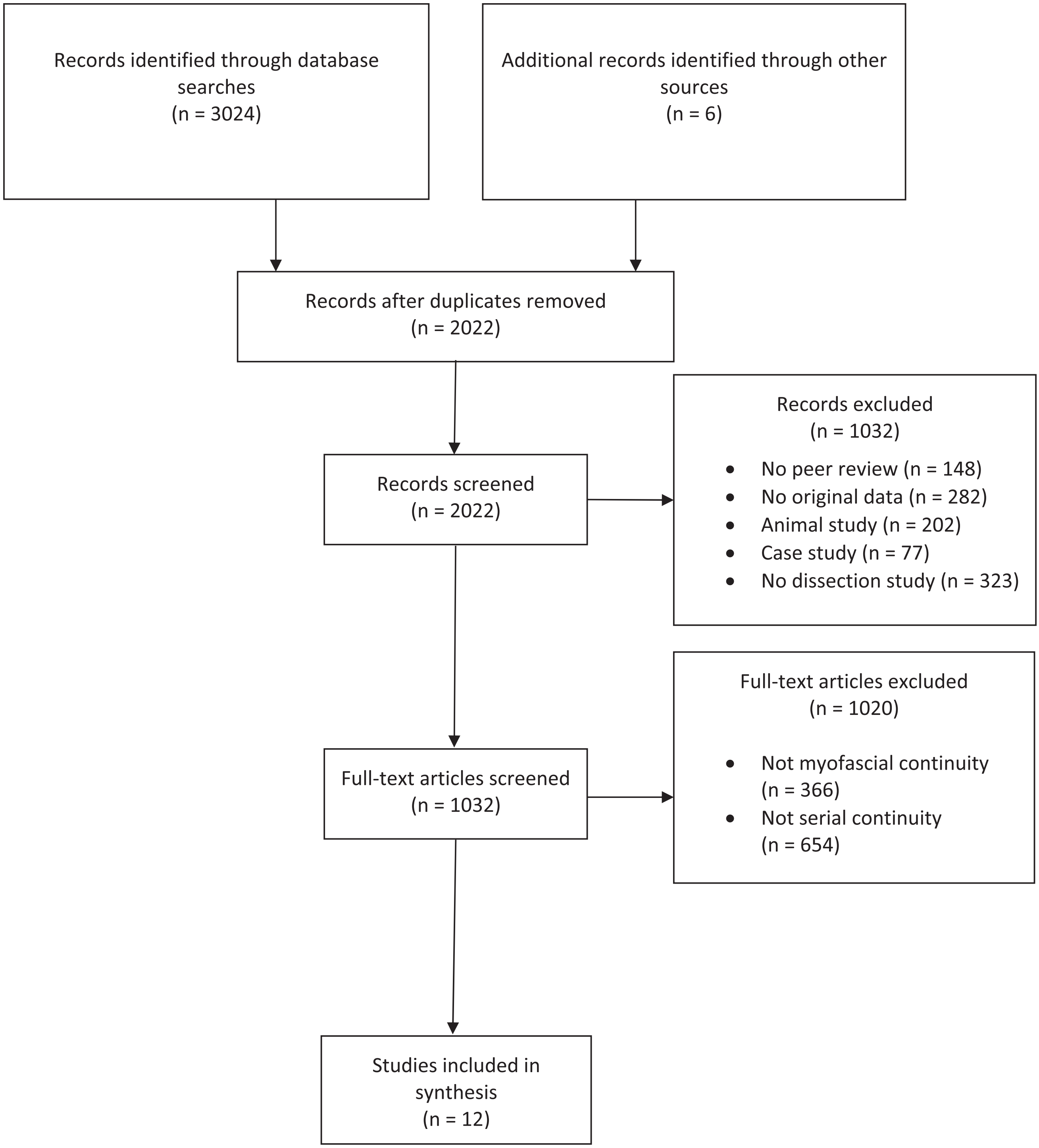

Fig. 1. Flow chart displaying the literature search.

1997), but these have not been based on published dissection work. As an example, Myers (1997), like others, proposed four arm lines, superficial and deep lines for both the front and back of the upper limb. Our results do not provide empirical support for three of these, but are almost exactly consistent with Myers's superficial back arm line (trapezius, deltoideus, lateral intermuscular septum, extensor group of the forearm).

Owing to the serial arrangement of the components of the myofascial chains identified in our search and to

TABLE 1. Quality Ratings (QUACS Scale) of the Included Studies

	Study purpose	Sample data	Method of dissection	Condition of specimens	Education of investigator	Multiple observers	Results precise	Statistics appropriate	Consistency of findings	Photographs included	Findings in context	Clinical relevance	Limitations addressed	Total score (%)
Dones et al. (2015)	✓	–	✓	✓	–	✓	✓	✓	✓	✓	✓	✓	–	77
Chafik et al. (2013)	✓	✓	✓	–	–	–	✓	n/a	✓	✓	✓	✓	✓	75
Day et al. (2009)	✓	✓	✓	–	✓	–	✓	n/a	✓	✓	✓	✓	–	75
Keener et al. (2010)	✓	✓	✓	✓	–	✓	✓	✓	✓	✓	✓	✓	✓	92
Molinier et al. (2011)	✓	–	–	✓	–	–	✓	n/a	✓	✓	✓	✓	–	58
Rispoli et al. (2009)	✓	✓	✓	✓	–	–	✓	n/a	✓	✓	✓	✓	✓	83
Stecco et al. (2007)	✓	✓	–	–	–	–	✓	n/a	✓	✓	✓	✓	–	58
Stecco et al. (2008)	✓	✓	✓	–	–	–	✓	✓	✓	✓	✓	✓	–	69
Stecco et al. (2009a)	✓	✓	–	–	–	–	✓	n/a	✓	✓	✓	✓	–	58
Stecco et al. (2009b)	✓	✓	✓	–	–	–	✓	n/a	✓	✓	✓	✓	–	67
Sun et al. (2015)	–	–	✓	–	–	–	✓	n/a	–	✓	✓	✓	–	42
Tubbs et al. (2009)	✓	–	–	–	–	–	✓	–	✓	✓	✓	✓	–	46

TABLE 2. The Three Identified Myofascial Chains with In-Series Continuity

	Transition	*N* (*n*)	*C*	Description
Dorsal arm chain	Latissimus dorsi—triceps brachii	2 (45)	60/60	According to two studies (Day et al., 2009, Stecco et al. 2007), there were fibrous connections between the latissimus dorsi tendon and the triceps brachii fascia in all cases examined.
	Teres minor/infraspinatus—triceps brachii	1 (31)	31/31	One study (Chafik et al., 2013) found a fascial sling attaching the combined fascia of the deltoid, infraspinatus and teres minor to the fascia of the triceps brachii.
	Triceps brachii—anconeus	3 (61)	50/51	Three studies (Keener et al., 2010; Molinier et al., 2011; Sun et al., 2015) reported that the lateral triceps brachii fused with the anconeus. Continuity width was 16.8 mm (Keener et al., 2010). Although Sun et al. (2015) did not report consistency of findings, Keener found the connection in all cases. Molinier et al. (2011) failed to detect a linkage in 1 out of 30 elbows.
	Anconeus—extensor carpi ulnaris	1 (45)	60/60	Day et al. (2009) and Stecco et al. (2007) described the anconeus and the extensor carpi ulnaris as being fused via fibrous septa taking origin at the internal surface of the posterior aspect of the antebrachial fascia.
Lateral arm chain	Trapezius—deltoideus	2 (45)	45/45	Two studies (Stecco et al., 2008; Day et al., 2009) reported a direct structural linkage between the fasciae of the trapezius and the deltoideus.
	Deltoids—lateral intermuscular septum/brachialis	4 (89)	92/95	Four studies (Stecco et al., 2008; Rispoli et al., 2009; Tubbs et al., 2009; Dones et al., 2015) described continuity of the middle deltoid and the lateral intermuscular septum. Although three studies (Stecco et al., 2008; Rispoli et al., 2009; Tubbs et al., 2009) detected a consistent linkage in all cases, one (Dones et al., 2015) found tissue fusion in only 17/19 arms.
	Lateral intermuscular septum—brachioradialis	2 (69)	69/69	Two studies (Tubbs et al., 2009; Dones et al., 2015) reported continuity between the lateral intermuscular septum and the brachioradialis in all cases.
	Lateral intermuscular septum—extensor carpi radialis brevis	1 (50)	50/50	One study (Tubbs et al., 2009) found a partial origin of the extensor carpi radialis brevis from the lateral intermuscular septum occurring in all arms examined.
Ventral arm chain	Pectoralis major—brachial fascia/biceps brachii	5 (96)	96/96	Five studies (Stecco et al. 2007, 2008, 2009a,b; Day et al., 2009) reported the pectoral fascia to fuse consistently and strongly with the brachial fascia. The biceps brachii is loosely attached to the latter but presents some direct fiber insertions (Stecco et al., 2009a).
	Biceps brachii—antebrachial fascia/flexor carpi radialis/brachioradialis	2 (45)	60/60	According to two studies (Stecco et al. 2007, 2009a,b), the flexor carpi radialis and the brachioradialis merge with the bicipital aponeurosis.

N, number of studies; *n*, cumulative sample size of all studies; *C*, consistency of findings.

the mostly strong fibrous continuity between the linked muscles, it is plausible that the tissue pathways do not merely provide structural cohesion. In agreement with bio-tensegrity models (Ingber, 2003; Levin and Martin, 2012) suggesting a complex mechanical inter-relationship among morphologically connected soft tissues (extending from the cellular to the macroscopic muscle level), forces can be transmitted between two myofascial chain components if the linkage between them can be made stiff enough. Initial evidence supports this claim, pointing toward functional and clinically relevant tissue continuity. In an attempt to mimic muscular contraction, Stecco et al. (2008) applied traction to the pectoralis major and observed visible stretches in the anterior aspect of the brachial fascia (ventral arm chain). Similarly, the authors noted displacements of the lateral intermuscular septum when deltoid was pulled (lateral arm chain). While these findings indicate nonmuscular mechanical coupling in the lower arm and shoulder region, further biomechanical research providing quantitative data is needed to elucidate the mechanical potential of the identified myofascial chains fully.

The three muscle-fascia lines could be of interest for physicians, movement therapists, and strength and conditioning coaches. In the myofascial chains of the trunk and lower limb investigated previously (Wilke et al., 2015), nonlocal abnormalities such as hypertonicity or altered muscle tone have been observed. As an example, patients with plantar fasciitis and low back pain frequently exhibit increased hamstring stiffness (Tafazzoli and Lamontagne, 1996; Labowitz et al., 2011). Proximally, the hamstrings are connected to the lumbar region via the sacrotuberous ligament. Distally, they fuse with the gastrocnemius fascia which, in turn, connects to the plantar fascia via its continuity with the Achilles tendon. Although there are few data regarding nonlocal abnormalities in pathologies of the shoulder-arm region, there could be similar inter-relationships here. It would be intriguing to examine whether patients with shoulder or neck pain exhibit altered local stiffness in the lower arm muscles (ventral chain with pectoralis major, brachial fascia/biceps brachi, flexor carpi ulnaris/brachioradialis/supinator, dorsal chain with latissiumus, triceps brachii, anconeus, extensor carpi ulnaris, lateral chain with trapezius, deltoideus, lateral intermuscular septum, and brachioradialis). On the other hand, changes of the shoulder muscles' mechanical properties could contribute to distal musculoskeletal disorders such as tennis elbow. Although they did not examine tissue stiffness in both body regions, Berglund et al. (2008) found a considerably higher prevalence of neck pain in patients with lateral elbow pain (70%) than in asymptomatic controls (16%). If this correlation were explained by mechanical force transmission across myofascial chains, this would fit with earlier descriptions of the elbow as a tensegrity structure (van der Wal, 2009; Scarr, 2012).

Experimental and histological studies suggest the strain transmission capacity of fascial tissues to be highest in the longitudinal plane, which corresponds to the muscles' line of pull (Eng et al., 2014). As a consequence, in-series connectivity, which is the central criterion for the choice of a myofascial chain's components, seems to be the prime candidate for effecting force transmission between two muscles. However, despite the muscle-fascia lines identified here, it needs to be underlined that myofascial continuity represents a global construction principle of the body rather than a specific feature of these chains. In many cases, in addition to the in-series linkages reported here, we found descriptions of tissue fusion with other muscles, for instance between the extensor carpi ulnaris and supinator (Imatami et al., 1999), which are located parallel to each other. A plethora of studies, mostly performed on the lower limbs of animals, have shown that mechanically relevant forces can be transmitted across such nonserial continuities (e.g., Maas et al., 2005; Huijing and Baan, 2008). Hence, although potentially maximal across the course of myofascial chains, strain will always be transmitted in multiple directions if local forces are modified.

CONCLUSION

In addition to the trunk and lower extremity, myofascial chains also appear to exist in the upper limb. According to the results of the present systematic review, three continuous muscle-fascia lines span between the shoulder and forearm regions. As data describing their functional relevance have been scarce to date, biomechanical studies quantifying mechanical force transmission are warranted.

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