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ORIGINAL COMMUNICATION

Dermatome and Fasciatome

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Increased knowledge of the rich innervation of the deep fascia and its anatomical organization indicates the need to reevaluate maps of the dermatome according to the new findings. The authors present a distinction between *dermatome* and *fasciatome*, basing their approach to the literature on nerve root stimulation and comparing dermatomeric and myomeric maps. The former represents the portion of tissue composed of skin, hypodermis, and superficial fascia supplied by all the cutaneous branches of an individual spinal nerve; the latter includes the portion of deep fascia supplied by the same nerve root and organized according to force lines to emphasize the main directions of movement. The dermatome is important for esteroception, whereas the fasciatome is important for proprioception. If they are altered, the dermatome shows clearly localized pain and the fasciatome irradiating pain according to the organization of the fascial anatomy. Clin. Anat. 32:896–902, 2019.

Key words: fascia; dermatome; nerve; pain; proprioception

INTRODUCTION

The textbooks now commonly used in medical and allied health programs contain multiple, conflicting dermatome maps (Ladak et al., 2014). The consequence for clinical practice is confusion in evaluating radiating pain. A "dermatome" is typically defined as the region of skin supplied by all cutaneous branches of a single spinal nerve (Kishner et al., 2017): it must be distinguished from the "myotome," which is the group of muscles innervated by a single spinal nerve, and from the "sclerotome," a region of bone and periosteum innervated by a single spinal segment (Inman and Saunders, 1944). The three maps do not overlap and, more importantly, they show completely different patterns, mainly in limbs.

Initial research to determine the extent of each dermatome was carried out in Europe during the late 19th and early 20th centuries. The first account of the distribution of segmental nerve fibers of the upper limbs was published in 1886 by Sir Wilmot Herringham, based on the results of his dissections of neonatal and adult cadavers (Herringham, 1886). Sir Henry Head was the first to produce a dermatome map based on clinical observation of referred visceral pain and traumatic lesions of the spinal cord (Head, 1893). During the late 19th century, Sir Charles Sherrington studied this subject further, using rhesus monkeys and severing the dorsal nerve roots above and below the nerve studied (Sherrington, 1898). A similar approach was also used by Otfrid Foerster to define the dermatomes of the lower limbs in humans (Foerster, 1933). In 1948, Keegan and Garrett published a radically different map, which has been reproduced in many textbooks (Keegan and Garrett, 1948). More recently, Denny-Brown et al. significantly altered the traditional view of a static dermatome map, in which the size of the dermatome

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changes according to the characteristics of adjacent spinal cord segments, indicating that the dermatome is in fact dynamic and dependent on central communications among spinal levels (Denny-Brown et al., 1973; Denny-Brown and Kirk, 1968; Kirk and Denny-Brown, 1970). Lee et al. (2008) constructed a new map based on clinical reports and studies of nerve block and peripheral nerve stimulation.

The current state of our knowledge indicates many discrepancies in the relevant literature, which hinders applications in clinical practice and causes difficulties for students (Challoumas et al., 2018). According to recent studies on deep fascia innervation, one explanation for all these different maps is that no study has distinguished the innervation of the skin from that of the deep fascia. However, we now know that the deep fascia is very well innervated (Hoheisel et al., 2011; Stecco et al., 2008) and that it could be a source of pain irradiation with different patterns from the skin (Schilder et al., 2014). Willard et al. (2012) introduced the term "fasciotome" to describe the specific innervation of the thoracolumbar fascia, according to the difference in innervation between the thoracolumbar fascia and the skin of the back. On the basis of that description, the present study reviews the literature on fascial innervation in order to ascertain whether the deep fascia can be innervated differently from the overlying skin and consequently have its own map of pain distribution.

METHODS

This article is not intended to be a comprehensive article, but rather a commentary review of published articles containing the terms "innervation," "fascia," "superficial fascia," or "deep fascia" in their titles. The PubMed database was searched for clinical studies with these key terms. Our research involved combining these terms using the Boolean operator "AND." It covered case reports, clinical trials, controlled clinical trials, reviews, comparative studies, multicenter studies, and randomized controlled trials in humans and other animals. Our search was expanded using the reference lists in these texts. Important secondary references were also used. Studies in English in which the word "fascia" is connected with "innervation" were examined; all other articles were excluded from the present review. A PubMed search for "innervation and fascia" yielded 791 articles. This number was reduced by eliminating 606 works on superficial fascia, subcutaneous tissue, hypodermis, nerves, tendons, and muscles. The remaining articles, indicating "innervation and deep fascia," totaled 185. When another search key word, "Pain," was added, the succeeding search for "Pain AND innervation AND deep fascia" yielded 37 papers (Fig. 1).

As a template for spinal nerve sensory distributions and peripheral nerve territories, we examined dermatome and myotome maps of the upper and lower limbs

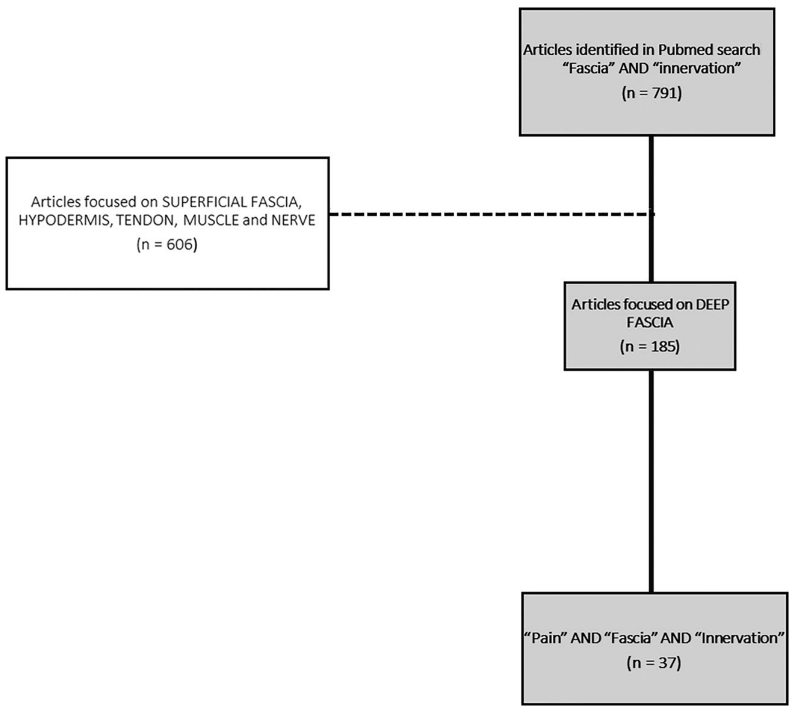

Fig. 1. Flow diagram illustrating published literature on fascial innervation and pain perception.

in the 41st edition of *Gray's Anatomy* (Standring, 2016) and also those described by Ladak et al. (2014), Furman and Stephen (2019), Slipman et al. (1998), and Schirmer et al. (2011).

RESULTS

Fascial Anatomy

The *Terminologia Anatomica* defines "fascia" as a sheath, a sheet, or any number of other dissectible aggregations of connective tissue. Consequently, two types of fascia are distinguished: the superficial fascia, which is connected to the skin, and the deep fascia connected by fibrous septa (*retinaculum cutis superficialis* and *profundus*, respectively), which impart specific mechanical properties to the subcutis (Nash et al., 2004). The two kinds of *retinaculum cutis* differ considerably (Lancerotto et al., 2011). The deep septa are rare, thin, and oblique, allowing great autonomy between superficial and deep fasciae. In contrast, the superficial septa are short, vertically oriented, and dense, connecting the superficial fascia to the skin (Stecco, 2015).

The deep muscular fascia is a fibrous layer that envelops not only all the muscles but also tendons, joints, and ligaments, connecting several elements of the musculoskeletal system and transmitting muscular force over a distance (Stecco, 2015). It can sense the basal tone of the underlying muscles because of its many muscular and tendinous insertions (Fig. 2); all these connections are called myofascial expansions. Marshall (2001) estimated that only 70% of muscular

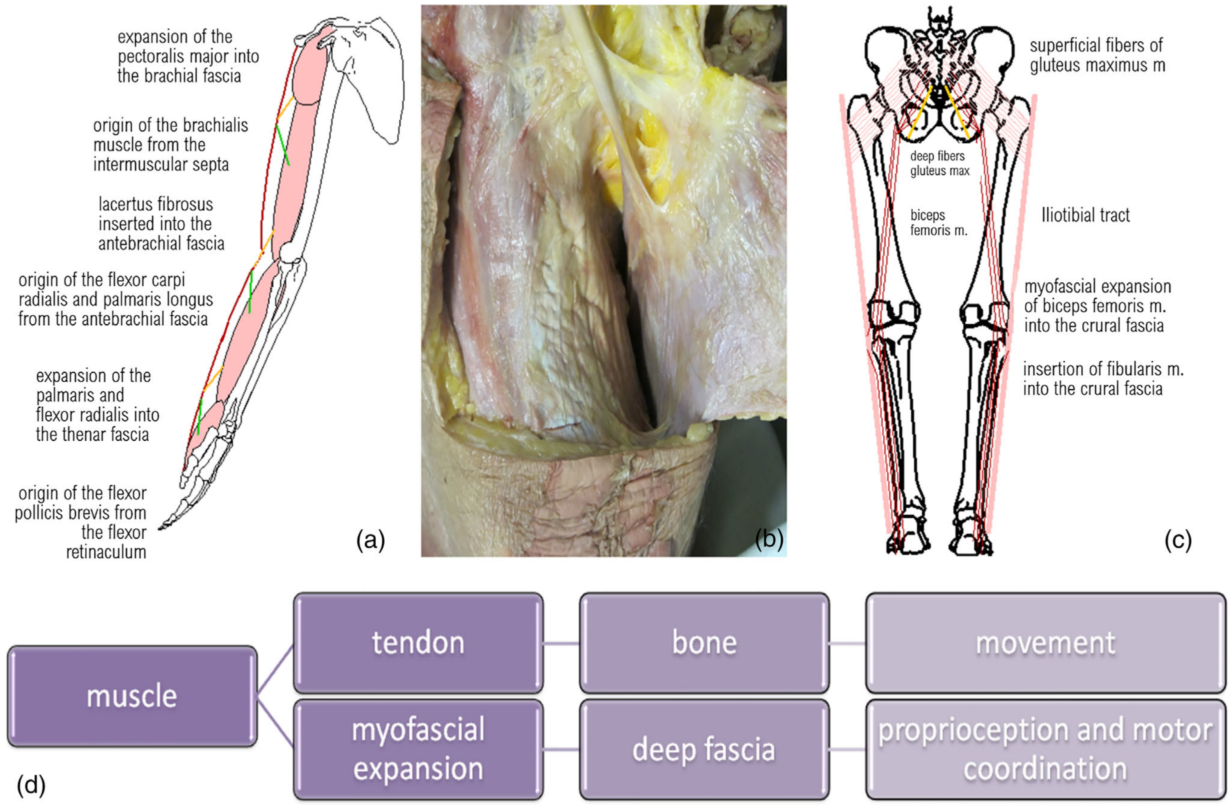

Fig. 2. (**a**), Schema representing myofascial expansions of anterior muscles of upper limb in which the continuity along the movement line of anteposition or flexion is highlighted. Note that pectoralis major, biceps brachii, flexor carpi radialis, and flexor pollicis brevis muscles have myofascial expansions into the brachial fascia, which is consequently tensioned each time the upper limb moves in an anterior direction. (**b**), Myofascial expansion of semitendinosus muscle into deep fascia. (**c**), Schema representing myofascial continuity along the line of movement of lateroposition or abduction allowed by the superficial fibers of gluteus maximus and tensor fasciae latae muscles, iliotibial tract, lateral parts of biceps femoris and vastus lateralis, and fibularis muscles. Along the line of retroposition or extension, the fascia is stretched by the deep fibers of gluteus maximus muscle, by ischiocrural and gastrocnemius muscles, to merge into plantar fascia. (**d**), Relative percentages of bone and fascial insertions of muscle, according to Marshall (2001). [Color figure can be viewed at wileyonlinelibrary.com]

forces are transmitted to the bones to perform movements; 30% are transmitted to the fascial components around the muscles. Thus, every time the muscles contract, they produce tension in the fascia and this mechanical input can create specific fibrous reinforcements day by day, visible macroscopically during dissection. Thanks to these myofascial connections, anatomical continuity is created among various muscles involved in the same directional movement, challenging the classical concept of muscles as morphologically independent actuators. Wilke et al. (2016) assigned a clinical application to these continuities along the body, demonstrating that the tension of the myofascial elements in the posterior region of the lower limbs can affect the range of motion (ROM) of the neck and that the consequent stretching of the ischio-crural muscles can improve that ROM.

Myofascial expansions are always present and show precise spatial orientation. In particular, they stretch the aponeurotic fasciae of the limbs along the six main directions of movement (Stecco et al., 2008): anteposition, retroposition, adduction, abduction, intrarotation, and extrarotation. We prefer the terms anteposition and retroposition to flexion and extension, because the hip and knee—for example, during a kick—perform both anteposition and stretching of the anterior portion of the fascia lata and crural fascia. According to the classical definition of such movements, the hip is flexed and the knee is extended, which seem to be opposite movements.

Innervation of the Fascia

Recent research shows that the deep fascia is richly innervated (Stecco et al., 2007; Taguchi et al., 2013; Tesarz et al., 2011) and could be active in proprioception and the perception of pain. The nerve fibers in the deep fascia can be either peptidergic or non-peptidergic. Taguchi et al. (2013) showed that the free nerve endings are both Aδ and C types. Aδ fibers appear to be sensitive mainly to mechanical stimuli such as clamping, whereas most C-type fibers are polymodal (nociceptors) and therefore sensitive to both mechanical and chemical stimuli (e.g., bradykinin) and to heat. In addition, C fibers in the deep fascia have a very high mechanical activation threshold (1,854 mN), about twice that of skin or muscle. Schilder et al. (2014) found that stimulation of the thoracolumbar fascia in healthy volunteers with hypertonic saline can generate pain, which is more intense and has greater irradiation than the same solution causes when injected into the muscular mass of the *erector spinae.* Similar results were obtained by Deising et al. (2012) with injections of nerve growth factor into the thoracolumbar fascia. Schilder et al. (2018) concluded that electrical stimulation of various soft tissues in the lower back reveals distinct pain quality patterns for muscles versus fascia and skin: the features of "deep pain" point toward muscle as the relevant target, whereas "heat pain" or "sharp pain" indicates the fascia. Schilder et al. (2018) also stated that the descriptor patterns of fascia and skin can lead to misinterpretation of fascia-related pain in the lower back pain as neuropathic. They also observed long-term sensitization of deep fascia nociceptors to mechanical pressure and chemical stimulation with acids. This mechanism could explain chronic musculoskeletal pain. In addition, the same authors showed that the free nerve endings of the fascia are stimulated most effectively when the fascia is "prestretched" by muscle contraction. Electrical stimulation of the deep fascia produces a dull, annoying pain, whereas the same stimulation of the hypodermis and superficial fascia produces acute and clearly localized pain (Itoh et al., 2004). This suggests that the two types of fascia have different roles: the deep fascia has a mainly proprioceptive function, whereas the superficial fascia cooperates with the skin for esteroception. The interposed adipose layer between the fasciae (DAT = deep adipose tissue) probably works by insulation, allowing the two fasciae to flow and be stretched independently. We suggest that the DAT should be viewed as the "watershed" between the exteroceptive system (formed of skin, superficial adipose tissue, and superficial fasciae) and the proprioceptive system (located in muscles and deep fasciae). Where the DAT disappears and the superficial and deep fasciae fuse (as in the palm of the hand and the plantar part of the foot), the esteroceptive and proprioceptive systems are combined. This facilitates the perception of form, volume, and the surfaces of various objects, and consequently movement, guaranteeing adaptation of the foot and hand to various contact surfaces. Anatomical variations are clearly recognizable and, predictably, dermatomal maps differ among individuals.

Taguchi et al. (2008) reported that the sensory endings project to spinal cord areas located in the dorsal horn, two to three segments cranially relative to the location of the terminal endings. This innervation pattern appears congruent with the underlying musculature. Chronic irritation of the muscle fascia can also induce sensitization at spinal level. Hoheisel et al. (2011) reported that the metamers affected by nociceptive afference increased in rats with chronic inflammation of the thoracolumbar fascia, and Taguchi et al. (2013) showed that repeated mechanical stimuli can stimulate the expression of c-Fos protein in the spinal metamers to which the sensitive fibers belong. Gibson et al. (2009) showed that the deep fascia—and not the muscle—is probably responsible for sensitization and/or pain associated with delayed onset muscle soreness following eccentric exercises. Hoheisel et al. (2015) reported an increase in SP-positive fibers (nociceptive) in a chronically inflamed thoracolumbar fascia, showing that the fascia can undergo pathological changes leading to long-term worsening of symptoms. Similar data were published by Sanchis-Alfonso and Rosellò-Sastre (2000) concerning the level of the lateral retinaculum of the knee, reporting growth of nociceptive, immunoreactive fiber substance P in patients with patellofemoral syndrome.

DISCUSSION

The works of Deising et al. (2012) and Schilder et al. (2014) clearly demonstrate that the deep fascia has a different pattern of pain irradiation from the overlying

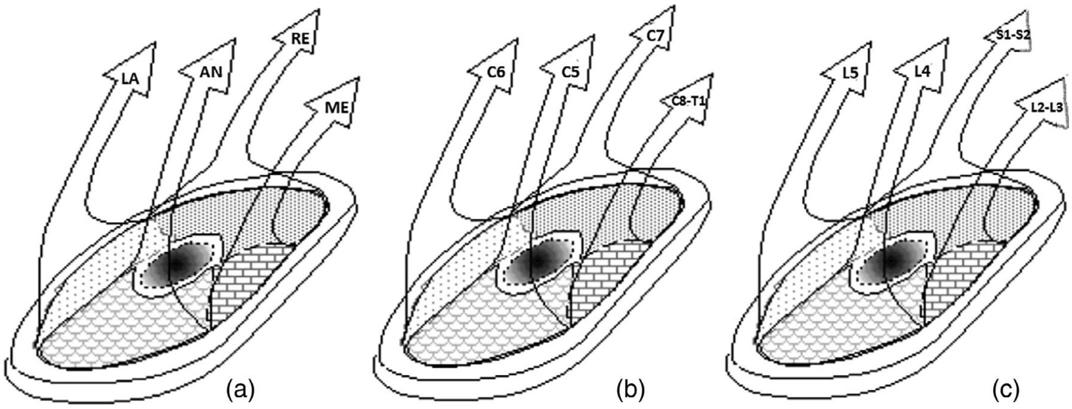

Fig. 3. Clockwise organization of nerve root distribution in limbs. The only difference between upper and inferior limbs is that adduction is perceived by distal nerve roots in the former, and by more proximal ones in the latter. This is probably due to limb rotation during embryological evolution, passing from quadrupedal to bipedal position. (**a**): movement line: anteposition (an) or flexion; retroposition (re) or extension; medioposition (me) or adduction; lateropostion (la) or abduction. (**b**): nerve root distribution in upper limb. (**c**): nerve root distribution in lower limb.

skin and underlying muscles: consequently, we must examine it separately. The organization of the fascia shows that the deep part is more closely related to muscles than to skin, both because there is a very large gliding plane between the superficial and deep fasciae, which guarantees considerable autonomy between the structures, and because the deep fascia is tensioned by myofascial expansions originating from the underlying muscles. The classification of somatic pain (Byers and Bonica, 2001; Coda and Bonica, 2001; Pasero et al., 1999) also combines pain related to the deep fascia with muscular pain (deep somatic pain), whereas the skin is related to superficial somatic pain. Consequently, the innervation patterns of the deep fascia probably follow myotomes rather than dermatomes. The anatomical organization of the deep fascia can also create a massive irradiation of pain along the fascial reinforcements, which follow a different pattern from the skin. According to this distinction, it is easy to explain the "anomalous" pattern of pain irradiation that does not follow a specific dermatome. For example, Furman and Stephen (2019) showed that during lumbosacral transforaminal epidural needle placement and injections, the distribution of symptoms often differs from that predicted by classic lumbosacral dermatomal maps. Slipman et al. (1998) also reported a discrepancy between radicular pain patterns and classic dermatome maps in the cervical spine. Murphy et al. (2009) concluded that in most cases nerve root pain should not be expected to follow a specific dermatome and that dermatomal distribution of pain is not a useful historical consideration for diagnosing radiculopathy. Kurosawa et al. (2015) and Murakami et al. (2017) reported that leg symptoms associated with sacroiliac joint disorder do not usually correspond to the dermatome (Kurosawa et al., 2015; Murakami et al., 2017). Bearing in mind the innervation of the deep fascia, the above authors attribute input to both skin and deep fascia during nerve root stimulation, creating an overlap of maps. In fact, maps of the skin and deep fascia probably overlap in the trunk, where the metameric organization of the muscles is maintained, but could diverge considerably in the limbs. In the latter, skin innervation follows the cutaneous nerves, whereas muscles show an entirely different pattern. When the nerve root is examined, not the motor nerves, all the muscles that stretch the deep fascia of the posterior compartment are clearly innervated by the same nerve root—in particular, from S1 in the lower limbs and C7 in the upper limbs (Furman and Stephen, 2019; Ladak et al., 2014; Schirmer et al., 2011; Slipman et al., 1998; Standring, 2016). Similarly, all the muscles stretching the deep fascia of the anterior compartments are innervated by L4 and C5; the muscles in the lateral region of the upper limbs are innervated by C6, and those in the lower limbs by L5. Lastly, the muscles in the medial region of the lower limbs are innervated by L3 and those of the upper limbs by C8 (Fig. 3).

Nerve root stimulation causes muscular contraction, allowing the bone to move, but it also stretches the overlying deep fascia thanks to myofascial expansions. As such, expansions are located along the main spatial directions, we suggest that all the fascial receptors along that line are stimulated during a movement in one direction, and consequently all these inputs coming from one line converge on a specific root. In this way, signals are pre-coded in the periphery, linking the perception of each motor direction to stretching of the receptors of a precise line of force inside the deep fascia. Most interestingly, pain referred to the buttocks, posterior thigh, or posterior calf cannot be due to radicular compression, but to excessive tension of the deep fascia along a specific line of force. This tension can activate all the free nerve endings along that line, giving rise to pain that simulates, for example, "S1 radiculitis." This could explain the symptoms of patients with predicted "S1 radiculitis" without imaging, supporting S1 pathology.

CONCLUSIONS

Knowledge of the rich innervation of the deep fascia and its anatomical organization indicates the need to reevaluate dermatome maps in the light of the new findings. Only the distinction between dermatome (the portion of tissue composed of skin, hypodermis, and superficial fascia supplied by all the cutaneous branches of a single spinal nerve) and the fasciatome (the portion of deep fascia supplied by the same nervous root and organized along the force lines for the four main directions of movement) can explain the main differences among dermatomeric maps reported in the literature. The dermatome is important for esteroception, whereas the fasciatome follows the precise patterns created from the deep fascia, which is important for proprioception. If altered, the dermatome gives clearly localized pain and the fasciatome irradiating pain, in accordance with the organization of the fascial anatomy.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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