Chapter 15

Fascia as sensory organ

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No longer an inert wrapping tissue

For most anatomical researchers, fascia was mainly considered an inert wrapping organ, giving mechanical support to our muscles and most other organs. Yes, there were some early histological reports about the presence of sensory nerves in fascia (Sakada, 1974; Stillwell, 1957), but these were largely disregarded and did not affect the common understanding of musculoskeletal dynamics. While both Moshe Feldenkrais and Ida Rolf, the founders of the related somatic therapies, were apparently not aware of the importance of fascia as a sensory organ, Andrew Taylor Still, the founder of osteopathy, proclaimed that, "No doubt nerves exist in the fascia…" and suggested that all fascial tissues should be treated with the same degree of respect as if dealing with "the branch offices of the brain" (Still, 1902).

Van der Wal reported, with painstaking detail, the substantial presence of sensory nerve endings in the fascia of rats, yet this finding was ignored for several decades (van der Wal, 1988). As far as ligaments were concerned, their proprioceptive innervation was recognized during the 1990s, which subsequently influenced the guidelines for joint injury surgeries (Johansson et al., 1991). Similarly, the plantar fascia was found to contribute to the sensorimotor regulation of postural control in standing (Erdemir and Piazza, 2004). However, what really changed the "view" in a more powerful manner was the first international Fascia Research Congress, held at Harvard Medical School in Boston in 2007. During the Congress, three teams from different countries reported, independently, their findings of a rich presence of sensory nerves in fascial tissues (Findley and Schleip, 2007). Following that event, several papers were published about fascial innervation, suggesting that the fasciae can be seen as our largest sensory organ in terms of overall surface area, but also that they can play an active role in proprioception and in the perception of pain.

Thanks to recent research insights, it is becoming evident that the fasciae are more complicated than anyone had thought. Indeed, the different fasciae have different type of innervation: the superficial fascia is more related with the exteroception and shares with the skin many nerve elements, the deep fasciae have above all free nerve endings including Pacini, Ruffini and spindle cell corpuscles for proprioception, the visceral fasciae have more an autonomic innervation (Stecco et al., 2017). Besides, spatial analysis indicates that in different areas there is a different density and types of nerve endings (Stecco et al., 2007) and, also in the same area, the various sublayers forming the aponeurotic fascia are innervated in a different way (Tesarz et al., 2011).

A detailed calculation by Martin Grunwald estimated the quantity of nerve endings in the body-wide fascial net as 100 million (Grunwald, 2017). This calculation related to the total mass of dense fibrous connective tissues only, which, based on Tanaka and Kawamura (2013) was estimated at 5 kg for an average male body. However, there are good reasons for also including the loose connective tissues in the calculation, not only because these tissues are part of the modern functional definition of the “fascial net” (see Chapter 1), but also because, based on Tesarz et al. (2011), we know that the loose subcutaneous connective tissue tends to express an even higher innervation density compared with the denser fascial layers underneath. Based on the data from Tanaka and Kawamura (2013), the mass of fibrous connective tissues in the human then increases to 12.5 kg (thus representing 17% of the total body weight). Taking this reasoning into account, the total quantity of nerve endings in the fascial net can then be estimated as ~2.5 times larger than the 100 million endings suggested by Grunwald, therefore arriving at the impressive number of 250 million nerve endings in the fascial net. Compared with an estimated quantity of 200 million nerve endings in the skin (Grunwald, 2017) or with the estimated 126 million endings for vision in our eyes, this new calculation suggests that the body-wide fascial network may possibly constitute our richest sensory organ.

Why sensory receptors?

Those of us who deal with the muscles and tissues of the human body often forget the importance of the sensory receptors. The brain, which is part of the central nervous system (CNS), is a very busy organ that requires its own army to continuously inform itself so that it can create movements that are accurate, opportunely timed, with proper force. Kendal et al. (2013) state that the brain relies on input from receptors in muscles, tendons, joints and skin to provide it with the information it needs to direct smooth and coordinated muscle movements. It therefore becomes extremely important for individuals who deal with any method of movement therapy to have an understanding of our potential influence on these sensory receptors. The CNS is directly responsible for all global movement directions such as raising our arms overhead, but must depend on sensory receptors for information about the movements of specific muscles.

Our bodies contain a somatosensory system containing sensory (afferent) neurons that respond to changes at the surface or inside our body. The somatosensory system regulates three major functions: proprioception, exteroception and interoception. Because this chapter is concerned with the sensory receptors of the fascial system, we will mainly be concerned with proprioceptive function. Proprioception refers to our ability to determine muscle activity and joint position. It is based on the stimulation of particular mechanoreceptors such as muscle spindle cells, Golgi tendon organs, joint capsule receptors and stretch-sensitive free nerve endings. Mechanoreceptors react when they are deformed by movement such as pressure, muscle stretch or contraction. These receptors produce and send sensory information to the brain, enabling it to detect the position and posture of the body and its parts. The sensory receptors that are classified as proprioceptors are the muscle spindles, Golgi tendon organs and joint receptors. Sometimes, Pacini and Ruffini corpuscles have a proprioceptive function, as they also report to the CNS regarding position. The CNS integrates information from proprioceptors and other sensory systems, such as vision and the vestibular system, to create an overall representation of body position, movement and acceleration. The sense of proprioception is essential for the motor coordination of the body. Proprioceptors can form reflex circuits with motoneurons to provide rapid feedback about body and limb position. These mechanosensory circuits are important for flexibly maintaining posture and balance, especially during locomotion.

Different types of sensory receptors in the fascial net

Free nerve endings

In the fasciae, we can recognize different types of sensory receptors, each one with a specific characteristic (Figure 15.1). Surely the most represented nerve receptors are the free nerve endings (Figure 15.2). They form a net, strongly connected with the extracellular matrix (viscous tissue providing support, segregating tissues from one another, and regulating intercellular communication) of the fasciae, and consequently they are particularly responsive to either stretch or shear loading. This is not surprising, since from a morphological and embryological perspective, the fascial net consists of those connective tissues that have adapted their architecture in response to a local dominance of tensional, rather than compressive loading (Schleip et al., 2012). The free nerve endings are very thin and delicate threads, sensitive to mechanical stimuli. Besides, if the extracellular matrix is altered or if

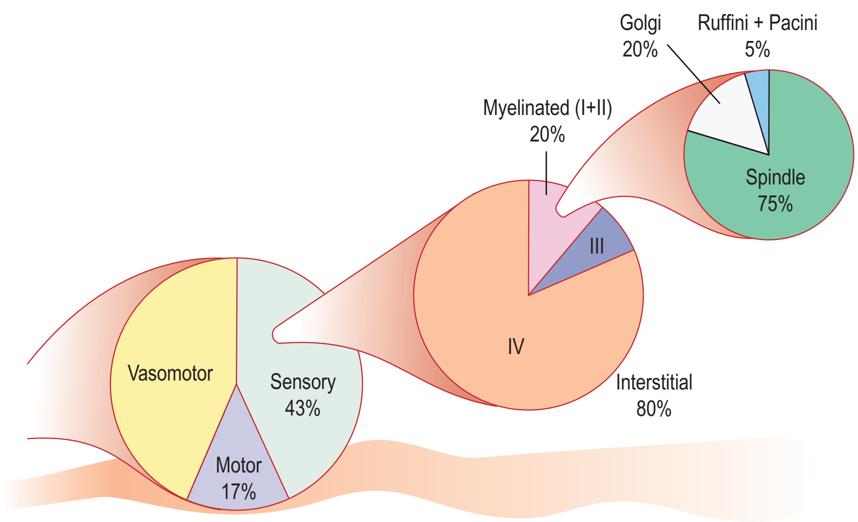

Figure 15.1 Composition of neurons in musculoskeletal connective tissues

The quantities of respective axons shown were derived from detailed analysis of the combined nerve supplying the lateral gastrocnemius and soleus muscle of a cat. While a small portion of the interstitial neurons may terminate inside bone, the remaining neurons can all be considered to terminate in fascia! tissues. Even the sensory devices called muscle spindles are nestled within fibrous collagenous intramuscular tissues. Interstitial neurons terminate in free nerve endings. Some of these clearly have a proprioceptive, interoceptive or nociceptive function. Recent investigations however suggest that the majority of the interstitial neurons in fascia serve a polymodal function, meaning that they are open for stimulation from more than one of these mentioned sensorial categories.

(Illustration courtesy offascialnet.com) the stimuli is too strong, these free nerve endings could also become nociceptors (pain receptors). Taguchi et al. (2013) have demonstrated that the mechanical activation threshold of the fascial free nerve endings is 2-fold greater than the skin and muscle. Schilder et al. (2014) demonstrated that the free nerve endings in the thoracolumbar fascia are more sensitive to chemical irritation compared with the underlying muscles, and that they can maintain a long-lasting hypersensitivity. Finally, Deising et al. (2012) have shown that the free nerve endings of the fascia are stimulated in the most effective way when the fascia is "pre-stretched" before muscle contraction. For health-oriented practitioners, it is important to realize that not all the free nerve endings can be classified as nociceptive. Some of them are sensory devices for thermoception, and others monitor muscular activity to the sympathetic nervous system to allow for a locally specific fine-tuning of the blood flow to respective muscle portions, which is then called ergoreception. Interestingly, in fascial tissues, the majority of the interstitial (between fibrous tissue) neurons are so-called polymodal receptors, meaning that they are responsive to more than one kind of stimulation. While their respective synapses in the posterior horn of the spinal cord are hungry and eager for any kind of stimulation, they seem to be easily satisfied if sufficient proprioceptive information is supplied to them via these polymodal receptors. However, in cases of alterations in the connective tissue matrix surrounding the respective nerve endings, these free nerve endings tend to actively lower their threshold for nociceptive stimulation, that is, expressing increased pain. In addition, they may actively give off cytokines that sensitize polymodal neurons in their neighborhood and predispose them towards a nociceptive function. A seemingly miniscule mechanical stimulation, such as a leg length difference of only 1 mm, can then lead to a nociceptive response within the intricate network of these intrafascial polymodal receptors.

In the fasciae there are four types of specialized mechanoreceptors (Stecco, 2015): Pacini, Ruffini and Golgi corpuscles, as well as the muscle spindles. Each type serves different functions accommodated by their different structures and activating stimuli. The Pacini corpuscles are rapidly adapting mechanoreceptors, so they decrease their discharge rate to extinction within milliseconds of the onset of a continuous stimulus. They are very sensitive to changes in stimulation and are therefore considered to mediate the sensation of joint motion, and may be more important in sports characterized by sudden directional changes, such as pivoting, shifting and tackling (Ergen et al., 2007).

Ruffini corpuscles are slowly adapting mechanoreceptors, so they remain discharging in response to a continuous stimulus. Ruffini are maximally stimulated at certain fascial tensions, and thus they can mediate the sensation of body position, but they are also highly sensitive to shear loading, so they can perceive a directional difference in tensional loading between one tissue layer and an adjacent one.

The muscle spindle receptor is a complex, fusiform receptor composed of several intrafusal muscular fibers, innervated by nerve fibers and surrounded by a strong capsule of connective tissue (Stecco et al., 2014). This capsule is in continuity with the perimysium of the surrounding muscle bundles, so the muscle spindles can perceive the tension developing inside the perimysium. We need to remember that it only takes a tension of 3 g to trigger a muscle spindle. This means that small alteration of the perimysium, as often happens after immobilization, can alter the threshold of these receptors, and this causes alteration in proprioception and muscle activation. Indeed, the muscle spindles play a key role in proprioception because they inform the CNS of the continually changing status of muscle tone, movement and position of body parts. Mense (2011) affirms that “structural disorders of the fascia can surely distort the information sent by the spindles to the central nervous system and thus can interfere with proper coordinated movement. Particularly the primary spindle afferents are so sensitive that even slight distortions of the perimysium will change their discharge frequency.”

Golgi endings are slowly adapting receptors that respond to tension. Stimulation of Golgi receptors tends to trigger a relaxation response in skeletal muscle fibers that are directly linked with the respectively tensioned collagen fibers. However, if tendinous extramuscular tissues are stretched in a condition in which they are arranged in series with muscle fibers that are in a relaxed condition, then most of the respective elongation will be “swallowed” by the more compliant myofibers. In this way, the respective stretching impulse may not provide sufficient stimulation for eliciting any muscular tonus change (Jami, 1992). A practical conclusion of this may be that a stretching impulse, aimed at reaching the tendinous tissues, may profit from including some moments in which the lengthened muscle fibers are actively contracting or are temporarily resisting their overall elongation.

While the Golgi receptors were previously considered to only exist in tendinous tissues, their presence in other fascial tissues has been confirmed by two independent studies (Stecco et al., 2007; Yahia et al., 1992). The Golgi corpuscles are located in the myotendineous junctions close to the intermuscular septa, and play a role in the coordination between agonist and antagonist muscles. So the Golgi endings can also contribute to the proprioceptive sense of force and heaviness of muscles.

The presence of the mechanoreceptors inside the fasciae is not homogeneous, for example, the Ruffini and Pacini corpuscles are located in the superficial fascia, while in the deep fascia they are present only where the proprioceptive inputs are stronger, as in the joint retinacula, and in the palmar and plantar fasciae. The muscle spindles are present only in the perimysium of the muscles and not in the thicker fasciae such as the thoracolumbar fascia and fascia lata.

Not all fasciae share the same innervation

Does it make a difference, which locations of the body-wide fascial network are stimulated in order to supply the spinal cord with new proprioceptive input? Two new insights regarding the density of sensory receptors in fascia provide valuable insight into this issue. First, the recent studies from the group around Mense at the University of Heidelberg have shown that in human and rat lumbar fascia, the density of sensory neurons is significantly higher in the superficial tissue layers between the dermis and fascia profunda compared with the respective density within the deeper tissue layer called lumbodorsal fascia, just underneath these superficial layers (Tesarz et al., 2011). In our own experimental examinations at Ulm University, we also observed an increased density of visible nerves in the transitional shearing zone between fascia profunda and fascia superficialis. In healthy body regions, this zone is where a lateral “skin sliding” movement, in relation to the underlying tissues, can easily be induced. It is also the zone whose architecture determines whether a skin fold can be pulled away from the body or not. It makes sense to assume that the lateral gliding movements given by everyday movements provide an important source of fascial proprioception. It is also an intriguing thought that the often profound reported therapeutic effects of various skin-taping techniques in sports medicine may partially be explained by their local amplification of respective skin movements in normal joint functioning.

The second recent insight regarding areas of increased density of sensory nerves in the fascial net comes from the Stecco group at Padua University in Italy (Stecco et al., 2007). Their histological examinations of upper and lower limb fasciae in human cadavers revealed huge differences in the density of proprioceptive nerve endings, such as Golgi, Pacini and Ruffini corpuscles. These recent data indicated that fascial tissues, which clearly serve an important force-transmitting function (such as the lacertus fibrosus on the upper forearm as an extension of the biceps femoris), hardly contain the same proprioceptive endings as the biceps fascia. On the other hand, they observed that some fascial structures seem to have very little role in force transmission, as witnessed when cutting them away, as is the case of the retinacula around the ankle and wrist regions. Interestingly, these more obliquely running fascial bands seem to be located at specific approximations to major joints and they contain a very high density of proprioceptive nerve endings (Figure 15.3). Some researchers suggest that the prime function of these fascial bands may not be their biomechanical but their sensorial function in providing detailed proprioception to the CNS. If verified, this could suggest that proprioception-enhancing approaches, whether in skin taping, yoga, stretching, foam roller self-treatment, or continuum movement-like micro movements, could each possibly be augmented

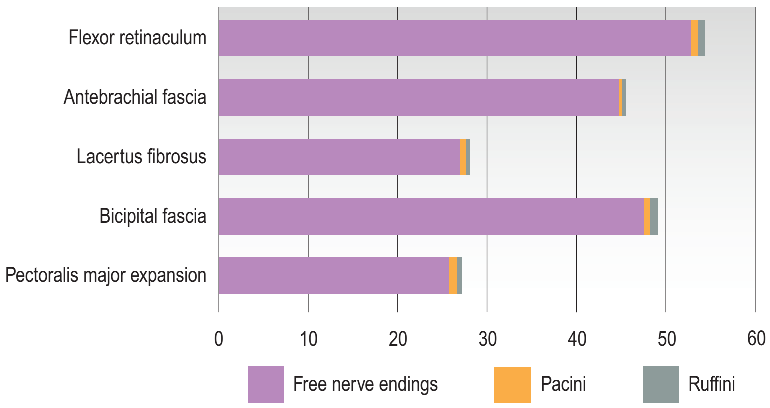

Figure 15.3
The mean number of the types of mechanoreceptors found in different areas of the upper limb (data from Stecco et al., 2007).

in their respective therapeutic effectiveness by stimulating fascial tissue movements in regions with an increased proprioceptive innervation.

Fasciae and pain

One of the most studied fasciae is the thoracolumbar fascia (TLF), because many studies have suggested that it can play a role in non-specific low back pain (Langevin et al., 2011; Schleip et al., 2007; Yahia et al., 1992). Indeed, the TLF is a densely innervated tissue and its free nerve endings can send nociceptive input to lumbar dorsal horn neurons (Taguchi et al., 2008). The work of Schilder et al. (2014) clearly demonstrated that the deep fascia, if altered, can be a prime candidate for pain, more so than muscles and subcutis. Injections of hypertonic saline into the deep fascia resulted in longer pain duration and higher peak pain ratings than injections into subcutaneous tissue or muscle. Also, pain radiation and pain affect evoked by fascia injection significantly exceeded those of the muscle and the subcutaneous tissue. The pain descriptors after fascia injection were burning, throbbing and stinging. After induction of delayed onset muscle soreness, pain thresholds of the fascia decrease significantly more than those of the underlying muscle tissue (Lau et al., 2015). Moreover, chronic irritation of the TLF can induce sensitization phenomena at the spinal level (Hoheisel et al., 2011). After experimentally induced chronic inflammation of the TLF, the density of nociceptive fibers was significantly increased from 4% to 15%. Also, the metamers affected by the nociceptive afference increased (Hoheisel et al., 2015). Similar results were reported in another fascia, the knee retinaculum, by Sanchis-Alfonso and Rosello-Sastre (2000), who highlighted the growth of nociceptive, substance P immunoreactive fibers in patients with patellofemoral syndrome. Pedersen et al. (1956) mechanically pinched the TLF of decerebrated cats and were able to elicit spastic contractions of the back muscles (mostly ipsilateral), as well as the hamstring and gluteal muscles (ipsilateral leg). Compared with pinching the underlying muscle tissues, the observed responses were much stronger in response to pinching the fascia. A similar result was obtained in the tibial anterior fascia of the lower leg. Taguchi et al. (2013) pinched the rat crural fascia and found an increased neural activation in the spinal dorsal horn.

Interoception and the insular cortex

An often overlooked aspect of fascial stimulation is the presence of interstitial nerves in fascia that serve an interoceptive, rather than proprioceptive or nociceptive, function. Stimulation of those free nerve endings provides the brain with information about the condition of the body in its constant search for homeostasis in relation to its physiological needs. Many of the respective free nerve endings are located in visceral connective tissues and constitute an important part of what is frequently referred to as the enteric brain. However, other interoceptive interstitial neurons are located within endomysial and perimysial intramuscular connective tissues. Interoceptive signaling is associated with feelings like warmth, nausea, hunger, soreness, effort, heaviness and lightness, as well as a sense of belonging or alienation regarding specific body regions (Craig, 2002).

The neural stimulation from the respective nerve endings does not follow the usual afferent pathways towards the somatomotor cortex of the brain, rather these neurons project to the so-called insular cortex, an internally folded area of cortical gray matter located inside the forebrain.

In this walnut-sized cortical area, perceptions about internal somatic sensations are associated with emotional preferences and feelings. People with disturbed functioning of the insula may still have full biomechanical functioning and achieve high IQ levels in respective tests; however, they are usually socially dysfunctional and unable to make reasonable decisions in complex situations (Damasio, 1999).

Whereas some health-related conditions, such as low back pain, scoliosis or complex regional pain syndrome, are associated with diminished proprioceptive acuity, other conditions seem to be more clearly related to dysfunctional interoceptive processing. These latter conditions include anorexia, anxiety, depression, irritable bowel syndrome, alexithymia (inability in recognizing and expressing one's own emotional states) and possibly fibromyalgia. It therefore makes sense that movement instructors, whether in yoga, pilates or martial arts, carefully examine their habitual preferences in fostering the direction of the suggested somatic curiosity of their clients. A rigid reliance on proprioceptive perception—"Where exactly is your lower back touching the ground?"—may provide limited long-term effects if applied to clients for whom a more interoceptive perceptual refinement approach may be required. In these cases, a skillful fostering of visceral fascial sensations, via specific yoga postures, for example, may sometimes provide more profound effects than the often habitual focus on musculoskeletal sensations (Table 15.1).

Table 15.1 Health conditions associated with dysfunctions in proprioceptive or interoceptive processing

Several pathologies have been shown to be associated with dysfunctions in proprioception. Other conditions are associated with an altered interoceptive processing. In the pathways of interoception, the insular cortex plays a leading role, in which all sensory input is combined with affective associations. In priopriocеption, the somatomotor cortex and its representational mapping of the body (body schema) are of central importance. Depending on the involved pathway of dysfunction, a different emphasis in fascia-oriented therapies may be indicated

Proprioceptive impairment	Interoceptive dysregulation
Low back pain	Eating disorders Irritable bowel syndrome
Whiplash	Post-traumatic stress disorder
Complex regional pain syndrome (CRPS)	Substance use disorders
Attention deficit hyperactivity disorder (ADHS)	Depression Panic disorder Generalized anxiety disorder
Scoliosis diagonal chain	Autism spectrum disorders Depersonalization/derealization disorder
Systemic hypermobility	Somatic symptom disorders Functional disorders
Other myofascial pain syndromes	Fibromyalgia Chronic fatigue syndrom

Conclusions

- Fascia constitutes a body-wide tensional network, which serves as our richest and most important sensory organ for perceiving changes in our own bodies.
- Related sensory nerves include receptors that clearly signal proprioceptive information.
- Visceral fasciae tend to primarily have an autonomic innervation, rather than a somatosensory one.
- Proprioceptive signaling tends to inhibit potential myofascial nociception, particularly if accompanied by a state of mindfulness and if the proprioceptive stimulation occurs in a body region, which is innervated by the same (or nearby) level of the spinal cord.
- The mutually inhibiting influences between myofascial nociception and proprioception seem to be particularly relevant in working with low back pain.
- Other smaller receptor neurons in fascia are focused on interoceptive or nociceptive sensations.
- Therapeutic enhancement of proprioceptive stimulation can be beneficial in many myofascial pain conditions.
- A skillful facilitation of interoceptive perceptions, on the other hand, may work equally well in several complex somatic dysfunctions by fostering an improved insular processing.

References

Bednar, D.A.1., Orr, F.W. & Simon, G.T. (1995) Observations on the pathomorphology of the thoracolumbar fascia in chronic mechanical back pain. A microscopic study. *Spine* 20: 1161–1164.

Craig, A.D. (2002) How do you feel? Interoception: the sense of the physiological condition of the body. *Nat Rev Neurosci*. 3: 655–666.

Damasio, A. (1999) *The feeling of what happens: body and emotion in the making of consciousness*. New York, NY: Harcourt-Brace.

Erdemir, A. & Piazza, S.J. (2004) Changes in foot loading following plantar fasciotomy: a computer modeling study. J Biomech Eng. 126: 237–243.

Ergen, E. (2007) Proprioception and Coordination, Bülent Ulkar, in Clinical Sports Medicine.

Findley T. & Schleip R. (eds.) (2007) *Fascia research Basic science and implications for conventional and complementary health care*. Munich, Germany: Elsevier Urban & Fischer.

Gibson, W., Arendt-Nielsen, L., Taguchi, T., Mizumura, K. & Graven-Nielsen, T. (2009) Increased pain from muscle fascia following eccentric exercise: animal and human findings. *Exp Brain Res*. 194: 299–308.

Grunwald, M. (2017) *Homo hapticus*. Munich, Germany: Droemer Verlag.

Jami, A. (1992) Golgi tendon organs in mammalian skeletal muscles: functional properties and central actions. *Physiol Rev*. 72: 623–666.

Johansson, H., Sjölander, P. & Sojka, P. (1991) A sensory role for the cruciate ligaments. *Clin Orthop Relat Res*. 268: 161–178.

Koike, S., Mukudai, S. & Hisa, Y. (2016) *Muscle Spindles and Intramuscular Ganglia/Neuroanatomy and Neurophysiology of the Larynx*. Tokyo, Japan: Springer, 11–20.

Liptan, G.L. (2010) Fascia: A missing link in our understanding of the pathology of fibromyalgia. *J Bodyw Mov Ther*. 14: 3–12.

McGlone, F., Wessberg, J. & Olausson, H. (2014) Discriminative and affective touch: sensing and feeling. *Neuron* 82: 737–755.

Mense, S. & Hoheisel, U. (2016) Evidence for the existence of nociceptors in rat thoracolumbar fascia. *J Bodyw Mov Ther*. 20: 623–628.

Mitchell, J.H. & Schmidt, R.F. (1977) Cardiovascular reflex control by afferent fibers from skeletal muscle receptors. In: Shepherd JT et al. (eds.) *Handbook of physiology*, Section 2, Vol. III, Part 2: 623–658.

Moseley, G.L.1., Zalucki, N.M. & Wiech, K. (2007) Tactile discrimination, but not tactile stimulation alone, reduces chronic limb pain. *Pain* 137: 600–608.

Sakada, S. (1974) Mechanoreceptors in fascia, periosteum and periodontal ligament. B*ull Tokyo Med Dent Univ.* 21(Suppl 0): 11–13.

Sandkühler, J. (2009) Models and mechanisms of hyper-algesia and allodynia. *Physiol Rev.* 89: 707–758.

Schilder, A., Hoheisel, U., Magerl, W., Benrath, J., Klein, S. & Treede, R.D. (2014) Sensory findings after stimulation of the thoracolumbar fascia with hypertonic saline suggest its contribution to low back pain. *Pain* 155:222–231.

Schleip, R., Jäger, H. & Klingler, W. (2012) What is 'fascia'? A review of different nomenclatures. *J Bodyw Mov Ther.* 16: 496–502.

Schleip, R., Naylor, I.L., Ursu, D., Melzer, W., Zorn, A., Wilke, H.J., Lehmann-Horn, F. & Klingler, W. (2006) *Med Hypotheses* 66: 66–71.

Standring, S., et al. (2009) *Gray's Anatomy: the Anatomical Basis of Clinical Practice*, 40th edn. Edinburgh, UK: Churchill Livingstone, 1101.

Stecco, C. (2014) *Functional atlas of the human fascial system.* Elsevier Health Sciences.

Stecco, C., Gagey, O., Belloni, A., Pozzuoli, A., Porzionato, A., Macchi, V., Aldegheri, R., De Caro, R. & Delmas, V. (2007) Anatomy of the deep fascia of the upper limb. Second part: study of innervation. *Morphologie* 91: 38–43.

Stecco, C., Sfriso, M.M., Porzionato, A., et al. (2017) Microscopic anatomy of the visceral fasciae. *J Anat.* 231: 121–128.

Stecco, A., Stecco, C. & Raghavan, P. (2014) Peripheral mechanisms contributing to spasticity and implications for treatment. *Curr Phys Med Rehabil Rep.* 2: 121–127.

Still, A.T. (1902) *The philosophy and mechanical principles of osteopathy.* Kansas City: Hudson-Kimberly, 62.

Stillwell, D.L. (1957) Regional variations in the innervation of deep fasciae and aponeuroses. *Anat Rec.* 127: 635–648.

Tanaka, G. & Kawamura, H. (1992) Reference Man Models Based on Normal Data from Human Populations. Report of the Task Group on Reference Man, The International Commission on Radiological Protection, Nr. 23. http://www.irpa.net/irpa10/cdrom/00602.pdf.

Tesarz, J., Hoheisel, U., Wiedenhöfer, B. & Mense, S. (2011) Sensory innervation of the thoracolumbar fascia in rats and humans. *Neuroscience* 194: 302–308.

van der Wal, J.C. (1988) The organization of the substrate of proprioception in the elbow region of the rat. PhD thesis. Maastricht, the Netherlands: Maastricht University, Faculty of Medicine.

Yahia, L., Rhalmi, S., Newman, N. & Isler, M. (1992) Sensory innervation of human thoracolumbar fascia. An immunohistochemical study. *Acta Orthop Scand.* 63: 195–197.