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FASCIA SCIENCE AND CLINICAL APPLICATIONS: HISTORICAL PERSPECTIVE

Fascia Research Congress Evidence from the 100 year perspective of Andrew Taylor Still

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Summary More than 100 years ago AT Still MD founded osteopathic medicine, and specifically described fascia as a covering, with common origins of layers of the fascial system despite diverse names for individual parts. Fascia assists gliding and fluid flow and is highly innervated. Fascia is intimately involved with respiration and with nourishment of all cells of the body, including those of disease and cancer. This paper reviews information presented at the first three International Fascia Research Congresses in 2007, 2009 and 2012 from the perspective of Dr Still, that fascia is vital for organism's growth and support, and it is where disease is sown.
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Andrew Taylor Still MD (1828–1917), an American Physician, was the founder of osteopathic medicine. A.T. Still lived in a time of medical uncertainty, during which many physicians were questioning drugs and techniques that were used, such as excessive bleeding and purging, and sought an alternative to traditional medicine. Dr. Still spent years studying and experimenting before he opened the American School of Osteopathy in Kirksville in 1892. His philosophy of osteopathy was based upon the concepts of body structure and health maintenance rather than disease. Dr. Still believed there were four basic principles: (1) The human body functions as a total biologic unit, (2) the body possesses self-healing and self-regulatory mechanisms, (3) structure and function are interrelated, and (4) abnormal pressure in one part of the body produces abnormal pressures and strains upon other parts of the body. He specifically described fascia as a covering, with attention to terminology which obscures common origins of individual parts of the fascial system. Fascia assists gliding and fluid flow and is highly innervated. Fascia is intimately involved with respiration and with nourishment of all cells of the body, including those of disease and cancer (Still, 1899, 1902, 1910).

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It is now more than 100 years and three international fascia congresses later, and advances in research methods and technology allow us to examine Dr Still's concept that fascia is vital for organism's growth and support, and it is where disease is sown. At the first International Fascia Research Congress we defined fascia broadly as: "the soft tissue component of the connective tissue system that permeates the human body, forming a continuous, whole-body, three-dimensional matrix of structural support. It interpenetrates and surrounds all organs, muscles, bones, and nerve fibers, creating a unique environment for body systems functioning. The scope of our definition of and interest in fascia extends to all fibrous connective tissues, including aponeuroses, ligaments, tendons, retinaculae, joint capsules, organ and vessel tunics, the epineurium, the meninges, the periosteal, and all the endomysial and intermuscular fibers of the myofasciae." This definition was refined at the second congress to specify particular structures or layers (Langevin and Huijing, 2009).

I was fortunate in 1988 to inherit the library of more than 100 journal articles collected by Dr Ida Rolf, PhD, which included the writings on fascia by AT Still. I knew there was important information there, but did not examine them closely until an Osteopathic student was doing a research rotation with me in 2012. The first three fascia congresses thus evolved from 2007 to 2012 without the benefit of guidance from Dr Still, but remarkably cover most of the concepts he proposed in his writings. Penetration, support and innervation were all presented at the first and second congresses but it was not until the third congress that fluid flow was addressed. Respiration and cancer remain for future congresses to explore. With this as a background, let us examine Dr Still's concepts one by one, comparing to information presented at the Fascia Research Congresses in 2007, 2009, and 2012. The full articles and keynote lectures are available on DVD recordings or in the conference proceedings book at www.fasciacongress.org. The introduction to each of the congress proceedings books provides brief statements about the importance of each of the papers included for that particular congress.

1) Fascia "…sheathes, permeates, divides and sub-divides every portion of all animal bodies; surrounding and penetrating every muscle and all its fibers—every artery, and every fiber" Still, 1899 page 163

Fascia is connective tissue that surrounds and connects every muscle and organ, forming continuity throughout the body. It is considered to be any dense irregular connective tissue sheet in the human body, including aponeuroses, joint capsules, or muscular envelopes such as the endo-, peri- and epimysium (Langevin and Huijing, 2009). The intramuscular extracellular matrix is composed of the endomysium, perimysium, and epimysium. The epimysium surrounds each muscle and is continuous with tendons that attach muscles to bones. The perimysium divides the muscle into fascicles or muscle fibre bundles. The endomysium is a continuous network of connective tissue that covers individual muscle fibers (Fig. 1). (P. Purslow, 2009; P. P. Purslow, 2002; Peter P. Purslow, 2010) (Yucesoy, 2009) Small fascial fibers extend to connect to the cell membrane itself (Fig. 2) (Passerieux et al., 2006).

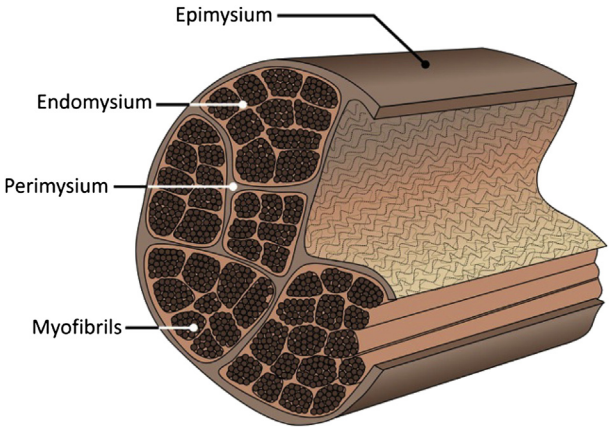

Figure 1 Schematic diagram of Intramuscular-extracellular matrix (IM-ECM) structures in a skeletal muscle. Epimysium delineates the surface of the muscle, perimysium separates muscle fascicles and endomysium separates individual muscle fibres. Also depicted are the contractile myofibrils within each muscle fibre. (Artwork: Dr. L.-T. Lim). From Purslow (2010).

Dissections and physiological studies have shown there are fascial connections resulting in myofascial force transmission between adjacent and even antagonistic muscles (Bojsen-Moller et al., 2010; Huijing, 1999, 2007; Kreulen, 2009; H. Maas and Sandercock, 2008; Huub Maas and Sandercock, 2010; Smeulders and Kreulen, 2007; Yu et al., 2007; Yucesoy and Huijing, 2007). The superficial fascia is a layer of areolar connective tissue or adipose tissue located directly beneath the skin. Fascial limb dissections show the extensive network of fascia throughout the limbs (A. Stecco et al., 2009; C. Stecco, 2009).

Deep fascia is tougher and contains denser connective tissue, containing and separating groups of muscles into well-defined compartments. Fascia plays an ectoskeletal role, creating a functional organization of muscles. Fascia also permeates through compartments, transmitting loads between them (Benjamin, 2009). The deep fascia in multiple specimens showed similar structural organization,

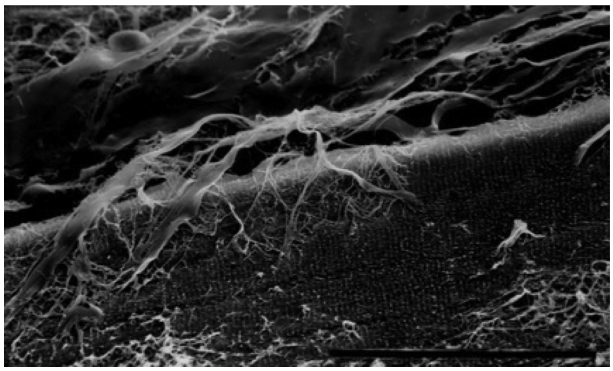

Figure 2 Scanning electron micrographs of the collagen fibre scaffolding in IM-ECM structures in bovine sternomandibularis muscle as revealed by NaOH-digestion of myofibrils, cytoskeletal proteins, cell membranes, and proteoglycans. High-magnification oblique view, showing endomysial networks. From Passerieux et al. (2006).

with ability to adapt to volume variations of muscles during contraction, and to resist high pressure without damage (A. Stecco et al., 2009).

2) "All organs have a covering of this substance, though they may have names to suit the organs, surfaces, or parts spoken of." Still, 1899 page 166

The connective tissue that surrounds muscle is not an isolated and independent entity; rather it is a continuous substance throughout the body. The broad definition of fascia allows fascial tissues to be seen as an interconnected tensional network that adapts its fiber arrangement, length, and density according to local tensional demands. Fascia forms linkages between muscular and non-muscular tissues at several locations in addition to tendon origins and insertions (Yucesoy and Huijing, 2007). For example, studies of the Achilles tendon in the foot have shown that the tendon not only attaches to the calcaneus, it is continuous with the plantar aponeurosis over the heel and the fibrous septa of the heel fat pad (Benjamin, 2009). Simply pulling or pushing one muscle leads to movement of its neighboring muscle, showing that muscles are unquestionably linked (Kreulen, 2009).

Fascia is traditionally named according to the discrete anatomic structure that it surrounds which obscures its four distinct layers (Willard, 2007). Fascia in different regions are named according to their regional anatomy, such as the fascia lata and iliotibial tract, the clavipectoral, axillary, brachial, and thoracolumbar fascia. It is considered to be "part of" organs or structures instead of a connective tissue continuum throughout the body, which unites and integrates different regions. The naming and studying of fascia in isolation is believed by some to be "barrier to understanding the bigger picture of fascial function" (Benjamin, 2009).

Dissection methods often start by "clearing" or "cleaning" structures from their connective tissue covering. Van Der Wal studied the interrelationships of muscle and other structures in the forelimb, using a fascia sparing dissection technique. He showed that muscular and joint connective tissues are continuous, not separate entities. He found that there are specialized connective tissue structures that are found between muscles and the bone of origin or insertion. This connection called the "dynament" can adapt to changes in distance between bones as joints open and close, unlike fixed length ligaments, which can only be of optimal length at one joint angle (Fig. 3). The continuity of fascia throughout the body can be attributed to its embryologic origin in the mesoderm (J. C. van der Wal, 2009a; J. C. van der Wal, 2009b). Connective tissue provides a structural framework for growth as it develops around structures of the body, continuously adapting and transmitting mechanical and chemical signals to differentiate tissue (D. E. Ingber, 2003).

The continuum of fascia throughout the body allows it to serve as a body-wide mechanosensitive signaling system (Langevin, 2006). Cells in living tissue are anchored

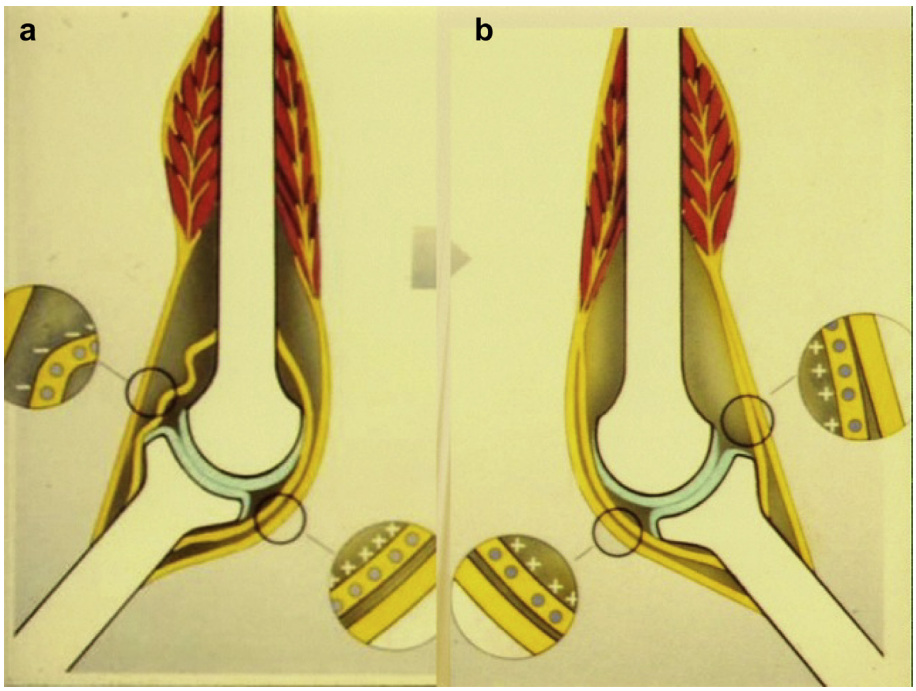

Figure 3 (a) The "classical" organization principle of juxta-articular connective tissue running from bone to bone, organized in parallel to the muscular component (tendons). From inside to outside: articular capsule; reinforcing juxta-articular regular dense connective tissue structures (ligaments); and on the outer side, periarticular muscle. Only in a particular joint position can the connective tissue transmit forces or signal in the sense of mechanoreceptor triggering (++++ versus ————). b) The alternative organization of juxtaarticular connective tissue organized in series to the muscular component. In all joint positions the connective tissue of the joint is brought to tension and is capable of transmitting forces and signaling in the sense of mechanoreceptor triggering (++++ and ++++). From van der Wal (2009b).

to the extracellular matrix through focal adhesions. At these sites, there are clusters of transmembrane receptors, known as integrins, that bind to ECM molecules on the outside of cells to anchor them in place. These integrins provide a path for mechanical stress to transfer across the cell surface and mediate signals within the cell to modulate growth, remodeling, and viability (apoptosis). Studies have confirmed that mechanical forces on cell surface receptors can immediately alter the organization and composition of molecules in the cytoplasm and nucleus of cells (Chen and Ingber, 1999; D. E. Ingber, 2007; Donald E. Ingber, 2010) Furthermore, the mechanical environment within the embryo is critical to its proper development (Mammoto and Ingber, 2010).

The amount and composition of the ECM is constantly changing based on the demands on the tissue and mechanical environment (Purslow, 2010). Fibroblasts in culture and in vivo respond to mechanical loads with measurable effects, such as extracellular calcium influx (through stretch-activated membrane channels), calcium-induced release of intracellular calcium stores, and the release of ATP. These studies indicate that tissue contraction and relaxation may result in a dynamic, body-wide pattern of cellular activity (Langevin et al., 2011, 2010). Furthermore the morphology of the embedded fibroblast changes from lamellar to dendritic, depending on the tensional status of the fascial network (Grinnell, 2000, 2007, 2008).

Fascia is also capable of transmitting electrical signals throughout the body. One of the main components of fascia is collagen. Collagen has been shown to have semiconductive, piezoelectric and photoconductive properties in vitro. Electronic currents can flow over much greater distances than ionically derived potentials. These electronic currents within connective tissue can be altered by external influences, and cause a physiologic response in neighboring structures (Langevin, 2006). However, exploration of the change in bone structures in response to stress (wolffs law) suggests that fluid flow within tissue is more important than piezoelectric effects (Ahn and Grodzinsky, 2009).

3) Fascia "gives all muscles help to glide over and around all adjacent muscles and ligaments" Still, 1899 page 164

All living cells also express some inherent contractility by generating tension within their internal cytoskeleton (Chen and Ingber, 1999). Fascia plays a dynamic role in transmitting mechanical tension, and may be able to contract in a smooth muscle like manner. In vitro studies of human lumbar fascia show that fascia can autonomously contract, hypothesized to be due to the presence of contractile cells within fascia. Fascia contains fibroblasts, which can transform into myofibroblasts which express a gene for alpha-smooth muscle actin (ASMA) and display contractile behavior (Schleip et al., 2005). The mechanical forces exerted by these cells regulate cytokine synthesis, production of extracellular matrix components and other processes essential to tissue remodeling (Hinz 2007; Hinz and Gabbiani 2010.).

The force generated by skeletal muscle fibers has been shown to spread throughout connective tissue, outside of the skeletal muscle and tendons (Benjamin, 2009; Huijing, 1999, 2007; Huub Maas and Sandercock, 2010). These are known as epimuscular myofascial pathways. Proof of these pathways has been shown by force measurements at the origin and insertion of muscle, as well as the demonstration that length changes in one muscle can affect forces in neighboring muscles kept at a constant length. These findings suggest that morphologically defined muscle is not the functional unit, as muscle length-force characteristics are variable depending on the conditions of other entities and cannot be considered a fixed property of the muscle. Furthermore, the sarcomere length within a given muscle may not be uniform along its entire length, resulting in the necessity for micro sliding at and within the muscle fiber level (Yucesoy, 2009).

Fascia aids in muscle contraction by several mechanisms. It links muscles together and to non-muscular structures via the myofascial pathways described above, and via the direct attachment of muscles into the connective tissue structure around the joint. For example, none of the muscle fibers of the supinator muscle insert directly onto the humeral epicondyle, but go instead to a connective tissue apparatus (J. C. van der Wal, 2009a; J. C. van der Wal, 2009b).

Over 200 vivo hand dissections show the complex network of connective tissue that facilitate sliding adaptation and mobility of structures within the body. Direct and mechanically adaptable multimicrovascular and fibrillar tissue connections between the tendon and the tendon sheath provide vascular access to the tendon. This tissue allows sliding of structures without any dynamic influence on surrounding tissues and can be found everywhere in the body, not just in tendon sheaths (Fig. 4) (J.C. Guimberteau, 2007; J. C. Guimberteau et al., 2010).

Furthermore, even within a single muscle, individual fibers must be able to slide next to each other as the muscle changes shape as it changes length. However, muscle fibers

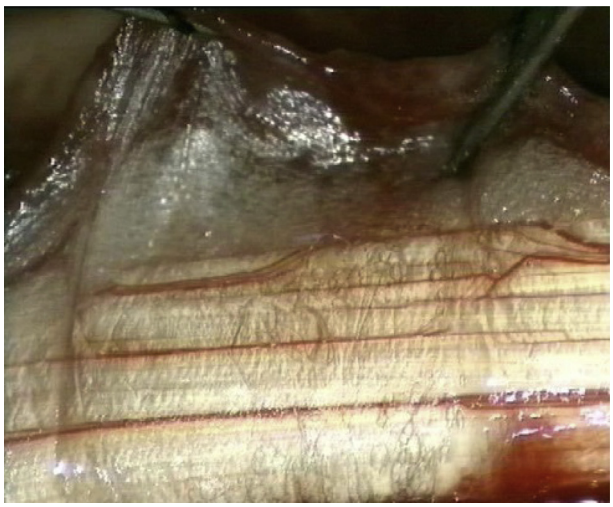

Figure 4 When the tendon moves, its movement is barely discernible in the neighboring tissue. The tendon may go far and fast without any hindrance. There is a micro-anatomical network between the tendon and the peripheral system which prevents a clear field of dissection between the paratendon and the tendon while at the same time it allows sliding. From Guimberteau et al. (2010).

can act in unison by shear force transmission across the very small distance of the endomysium (P. Purslow, 2009).

Loose connective tissue present between the deep fascia and underlying muscles permits sliding of muscles (C. Stecco, 2012). This has also been demonstrated by dynamic ultrasound imaging of layers of the thoracolumbar fascia (Langevin, 2009). There is also a layer of lubricating hyaluronic acid between the deep fascia and the muscle, about 100 microns thick (Fig. 5) (McCombe et al., 2001) which is just at the limit of resolution of newer musculoskeletal ultrasound equipment. Collagen sheets that form layers of connective tissue promote skin sliding and stretching, and allow the skin to maintain its original shape (Benjamin, 2009). Fascia plays an important role in separating and organizing muscle groups into compartments. The groups of synergistic muscles are believed to increase the efficiency of muscle contraction, as it has been shown that a small elevation in pressure within each compartment can increase the contractile efficiency of all of the members within the group (P. P. Purslow, 2002).

4) Fascia functions by "secreting and excreting fluid vital and destructive. By its action we live, and by its failure we shrink, swell, and die....This connecting substance must be free at all parts to receive and discharge all fluids, if healthy to appropriate and use in sustaining animal life, and eject all impurities that health may not be impaired by the dead and poisoning fluids." Still, 1899 page 164.

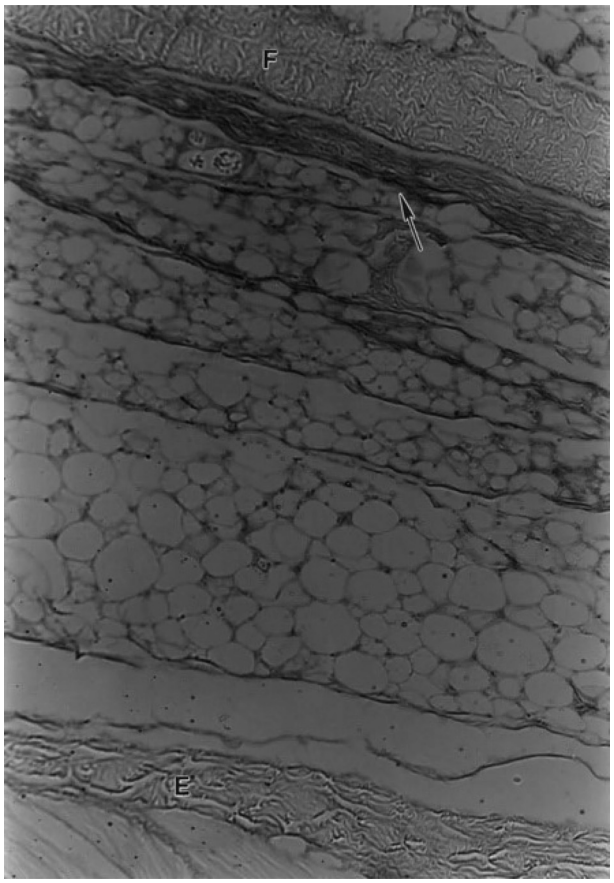

Figure 5 Interface between the deep fascia and epimysium (hyaluronic acid binding region stain 6165). Hyaluronic acid localized to the deep or muscular surface (arrow) of the deep fascia (F). The epimysium (E) is less intensely stained than the fascia. From McCombe et al. (2001)..

Loose connective tissue harbors the vast majority of the 15 L of interstitial fluid (Reed et al., 2010; Reed and Rubin, 2010). This flows through an extracellular matrix which contains cells such as fibroblasts, tumor cells, immune cells, and adipocytes. Interstitial fluid flow can have important effects on tissue morphogenesis, function, cell migration, differentiation, and remodeling, and fibroblast cells embedded in the extracellular matrix align themselves perpendicular to the direction of fluid flow. Variations of content of water, ions and other substances can alter the biomechanical properties of loose connective tissue. The slightest change in fluid flow can alter the shear stress on a cell surface and the biochemical environment of the cell. Interstitial flow regulates nutrient transport to metabolically active cells and plays a crucial role in maintaining healthy tissue. It can also give directional clues to cells by guiding lymphocytes and tumor cells to lymph nodes or towards lymphatic capillaries (Rutkowski and Swartz, 2007).

Blood flow to skeletal muscle is tightly regulated by its metabolic demands. When muscles contract, the local arterioles rapidly dilate by a mechanism which is not regulated by the skeletal or autonomic nervous system but rather by a direct mechanical connection. Tensile forces from contracting skeletal muscle alter the conformation of fibronectin fibrils running from the muscle to the nearby arteriole. This pulls open the nitric oxide receptor and causes local vasodilation (Hocking et al., 2008).

Inelastic fascia can promote lymphatic flow. When muscles contract against a thick, resistant fascia layer, it increases the pressure within a compartment, and permits blood and lymphatic fluid pumping against gravity towards the heart (Benjamin, 2009).

Fluid volume is regulated by interstitial hydrostatic and colloid osmotic pressures, which are constantly readjusting due to alterations in capillary filtration and the lymphatics. Connective tissues can alter transcapillary fluid flux by altering cell tension on dermal fibers which surround the hydrophilic ground substance and prevent its osmotic pressure from drawing fluid out of the capillary. When these fibers relax, this allows glycosaminoglycan ground substance to expand and take up fluid, resulting in edema formation (Fig. 6). After injury, fluid flow can increase almost 100 fold within minutes; most of this is due to the active osmotic pressure of the extracellular matrix rather than to capillary leakage which only increases 2 fold (Reed et al., 2010; Reed and Rubin, 2010).

Compartment syndrome is a painful and potentially limb-threatening condition that occurs when there is an increase in pressure within the deep fascial compartment which impairs blood flow (Benjamin, 2009).

5) Fascia "...is almost a network of nerves, cells and tubes, running to and from it; it is crossed and filled with, no doubt, millions of nerve centers and fibers...Its nerves are so abundant that no atom of flesh fails to get nerve and fluid supply there from...The cord throws out

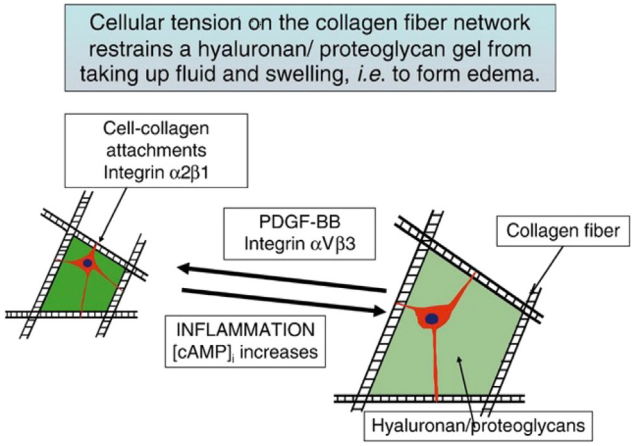

Figure 6 Proposed mechanism for dynamic control of interstitial fluid pressure (PIF). Dextran anaphylaxis, prostaglandin E1 and antibodies toward α2β1-integrin loosens the cell attachment on the collagen fibers and the tissue swells due to the content of hyaluronan and glycosaminoglycans. The decreased compaction lowers PIF and causes fluid influx. Platelet-derived growth factor BB (PDGF−BB), insulin and prostaglandin F2α causes connective tissue cells to compact the collagen fibers resulting in restoration of the normal compaction and normal PIF of the tissue. From Reed et al. (2010).

and supplies millions of nerves by which all organs and parts are supplied with the elements of motion, all to go and terminate in that great system, the fascia." Still, 1899 Page 164−5

Fascia is richly innervated. (J. C. van der Wal, 2009a; J. C. van der Wal, 2009b) Nerves have a three-fascial layer structure. Endoneurium covers individual axons, perinurium covers bundles of axons, and the epineurium is a thicker layer that covers the perineurium. All layers of the nerve are innervated, and have a plexus of nociceptors (Bove, 2007, 2008). Fascia contains abundant free and encapsulated nerve endings, and they have been described in the thoracolumbar fascia, the bicipital aponeurosis, and various retinacula (Benjamin, 2009). Nerve fibers are found in deep fascia (Bhattacharya et al., 2010). The thoracolumbar fascia (TLF) is densely innervated with different nerve ending distributions in different facial layers (Fig. 7). Free sensory nerve endings supply nociceptors. Sensory thoracolumbar fascia fibers give input to lumbar dorsal horn neurons, indicating that this may be a source of lower back pain (S. Mense, 2007; J Tesarz, 2009; J. Tesarz et al., 2011).

Fascia plays an important role in proprioception. Muscle spindles are not located uniformly within muscle, but concentrate in areas of force transmission to the fascia surrounding the muscle (Fig. 8) (J. C. van der Wal, 2009a; J. C. van der Wal, 2009b). A specific pattern of proprioceptor activation occurs when there is fascial tension, and it is directly associated with the deep fascia's relationship to muscle (Benjamin, 2009).

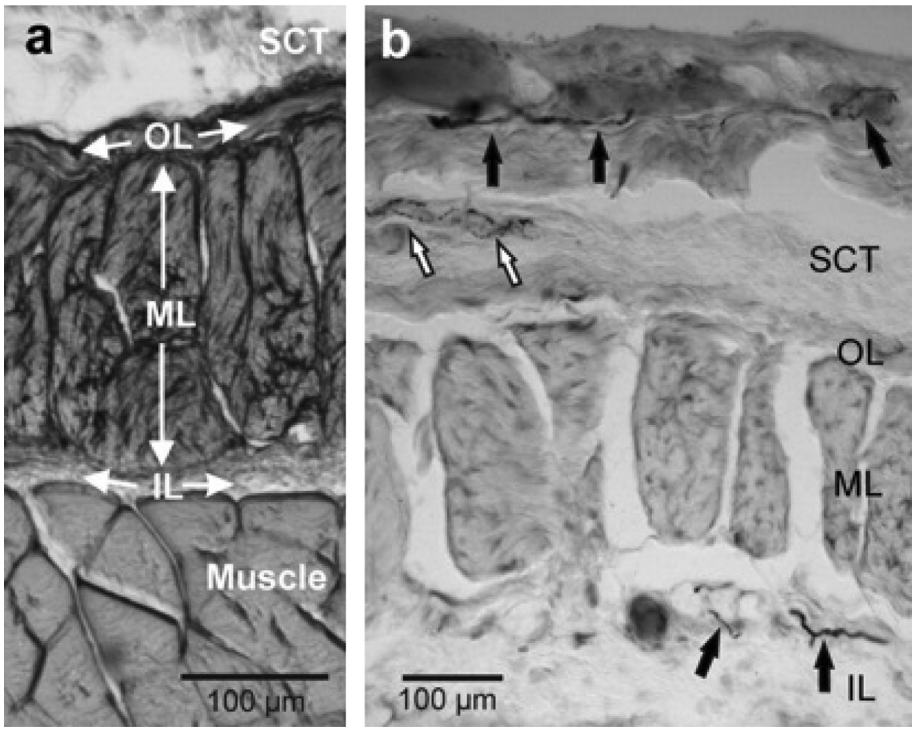

Figure 7 Structure of the rat thoracolumbar fascia (TLF) close to the spinous processes L4/L5. (a) Transversal section showing the three layers of the TLF (hematoxylin and eosin staining): OL, outer layer with transversely oriented collagen fibers; ML, middle layer composed of collagen fiber bundles oriented diagonally to the long axis of the body; IL, inner layer of loose connective tissue covering the multifidus muscle (muscle). SCT, subcutaneous tissue. (b) PGP 9.5-ir nerve fibers in the layers of the TLF. Black arrows, fibers on passage; open arrows, nerve endings. From Tesarz et al. (2011).

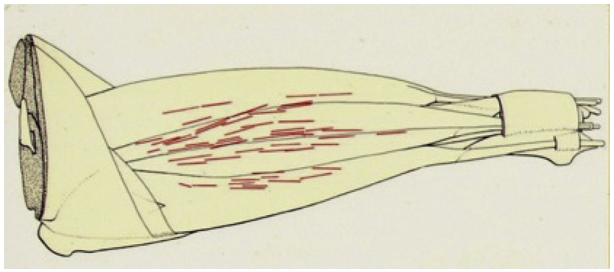

Figure 8 The spatial distribution of muscle spindles in the superficial lateral forearm muscle in the rat. The distribution is clearly more related to the architecture of the proximal epicondylar connective tissue apparatus than to the topography of the muscles. The spindles are presented as thin black lines. The thicker lines in the diagram represent the intermuscular septa that are part of the proximal regular dense connective tissue (RDCT) apparatus (on the left) and the distal tendons of the superficial extensor muscles (on the right). From van der Wal (2009b).

Fascia contains several terminal endings of nociceptors, responsible for muscle pain. Nociceptors detect stimuli that are capable of damaging tissue such as mechanical overloading and trauma, and inflammatory mediators such as bradykinin, serotonin, and prostaglandin E2 (S. Mense, 2007; Siegfried Mense, 2008). Muscle nociceptors, imaged by light and electron microscopy, were found to be present in all types of tissues within muscle: connective tissue, extrafusal and intrafusal muscle fibers, adventitia of arterioles and venuoles, fat cells, and tendons (Bhattacharya et al., 2010). These nerve endings directly transduce noxious mechanical stimuli. The in vivo response of individual mechano-nociceptors is dependent on their physical connection to the ECM (Khalsa, 2004, 2007).

6) "If disease is so highly attenuated, so ethereal, and penetrable in quality, and multiple in atoms; and a breath of air two quarts or more taken into the lungs fully charged with contagion, how many thousand air cells could be impregnated by one single breath?...-Nourishment from the vitality found in the human fascia, which comes nearer to the surface in lungs than any part of the system…" Still, 1899 page 168–9

A.T. Still wrote about the importance of breathing to nourish the body. This area remains to be addressed in future fascia congresses as more knowledge is gained. Theoretical basis, mechanistic studies, and outcome measures are needed. Projects on respiration and fascia are strongly encouraged to be submitted as abstracts for the Fourth International Fascia Congress to be held in Orlando Florida, October 15–17 2015. A few readings are suggested for those interested in developing this topic (Chaitow and Bradley, 2002; Gilbert and Chaitow, 2002; Thomas and Klingler, 2012) including the autonomic influence on fascial contractility, which could be a mechanism connecting respiration and the fascia (Brils et al., 2012).

A.T. Still recognized the importance of fascia in health, and recent research has shown that many of his ideas about fascia are valid. Fascia has been gaining increasing interest from physicians and manual therapists. Manual therapy techniques treat the fascial layers by altering density, tonus, viscosity, and the arrangement of fascia (Crane et al., 2012; Pohl, 2010; Simmonds et al., 2012). The manual stimulation of sensory nerve endings may lead to tonus changes in muscle. The fascial system is now being recognized as the etiology of pain and proprioception. Myofascial trigger points are local thickenings of individual muscle fibers that are caused by contractions of a small group of sarcomeres (Siegfried Mense, 2008). Fascia research can help understand aspects of musculoskeletal problems such as myofascial trigger points, low back pain, and fibromyalgia. Connective tissue is also intimately associated with other tissues and organs, so it may influence the normal or pathological processes in a wide variety of organ systems.

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