Clinical Anatomy 32:871–876 (2019)

REVIEW

Educational Avenues for Promoting Dialog on Fascia

REBECCA L. PRATT *

Department of Foundational Medical Studies, Foundational Medical Studies, Oakland University William Beaumont School of Medicine, Rochester, Michigan

If your healthcare professional students have not heard about the importance of fascia they definitely should, and if your residents have not heard about the manifestations of fascia health they definitely will from their patients. While fascia may not be the sexiest of organ systems, it is one of the most influential. Fascia is gaining interest from researchers, physicians, and many subdivisions of manual medicine including massage therapists. The fascial system is now being recognized with roles in pathology, fluid movement, and proprioception. It is also important in skeletal muscle movement, perception of pain, protein regulation and expression, cell signaling, neoplastic growth, and hormone distribution in our body. It can be the reason why we feel chronic pain or why we feel tightness after physical activity. The primary responsibility of fascia is to connect systems so that the body works as a whole, which is what permits this topic to be easily embedded anywhere in our health curricula. Whether you teach students in schools of medical, veterinary, dental, physical therapy, physician assistant studies, or occupational therapy, fascia matters. Whether you teach in an integrated curriculum or a curriculum that is designed for problem-based learning or a classical discipline-based curriculum, connective tissue has a place in academia. So, in our cramped curriculum how do we make sure that our current undergraduate and graduate students understand the complexity of fascia without adding additional time to coursework? To answer this question, this article demonstrates how fascia can fit anywhere in the curriculum because it is found everywhere. Clin. Anat. 32:871–876, 2019.

Key words: fascia; connective; tissue; curriculum; anatomy

INTRODUCTION

"A knowledge of the universal extent of the fascia is imperative, and is one of the greatest aids to the person who seeks the causes of disease. The fascia and its nerves demand his attention, and on his knowledge of them much of his success depends..." (Still, 1899).

Fascia is the interface between structure and function. The fascial system of the human body surrounds all organs, muscles, bones, and nerves. It provides an environment that enables all body systems to operate in an integrated manner. The fascial framework is continuously adapting and transmitting mechanical and chemical signals to all tissues of the body (Findley et al., 2015). It is this continuum of fascia throughout the body that allows it to serve as a body-wide mechanosensitive signaling system. Fascia has a large role not only in maintaining static posture but also in dynamic movement and efficient energy transfer throughout the body. It maintains a perpetual relationship (physically, mechanical, and biological) between cells and the other tissues to which it connects.

Simply speaking, fascia provides an environment that enables all body systems to operate in an integrated manner. For example, cartilage and bone, both types of

*Correspondence to: Rebecca L. Pratt, Department of Foundational Medical Studies, Oakland University William Beaumont School of Medicine, Rochester, MI 48309. E-mail: rebeccapratt@oakland.edu

Received 22 January 2019; Revised 22 March 2019; Accepted 30 March 2019

Published online 17 April 2019 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/ca.23380

specific connective tissues, contribute to the strength and resiliency of the body. Modifications to structural protein fibers make fascial types flexible or elastic and therefore tissues that are malleable (Willard et al., 2012). Besides the fibrous component of fascia, the connective tissue contains a high density of glycoproteins that act as water sponges. This property contributes to the body's aqueous environment for cellular communication and overall health (Findley et al., 2015). The various cellular components of fascia allow this tissue to carry out specific functions for specific regions and organs of the body (Langevin, 2006). Slight variations to the type of cell and the percentage of cell type present create a whole-body continuum instead of discrete, isolated pockets of named connective tissue. Fascia helps us better understand how all the seemingly distinct parts of our physiology are assembled into a coherent whole.

As educators, we are continuously adapting our learning environments to foster student-centered learning and critical, clinical thinking. In a way, fascia is doing the same things within our bodies. Fascia is continuously adapting to our body's needs, habits, and health changes. For years anatomists researching movement, pain, fitness recovery, disease control, and containment were literally removing and discarding the one tissue that was intimately involved. The "fascia in the trash" was what was holding many of the answers that medical researchers were seeking.

Now that we have a basic understanding of what fascia is, how do we in our cramped curriculum make sure that our current undergraduate and graduate students understand the complexity of fascia *without* presenting it as one isolated topic? Since fascia is everywhere, you use it as a foundation for every discipline.

Gross Anatomy

Fascia serves as one of the body's fundamental "connectors." Visualizing the amazing range of fascia at the gross level, from fat to tendons, is a good first introduction for students in dissection or prosection. No matter how it is taught at your institution, gross anatomy is a curricular staple and perhaps the easiest discipline to help students grasp the concept of fascia. Set aside the complexity of fascia within prosection or dissection for a moment and use a familiar object to teach the concept. An orange; a beautiful example of how fascia dictates the structure and form. Bring an orange to the lecture hall or to each team-based learning unit and initiate discussion by asking the students to peel the fruit. Some students may know that "softening" the orange by applying pressure to the outer rind of the fruit and rolling it on a hard flat surface will make the rind easier to peel. This teaching moment allows the instructor to explain that by pressing on the orange and rolling it you are disrupting collagen fibers running between the rind and the deeper fascia compartmentalizing the pulp of the orange into wedges. When the rind is removed, remnants of the superficial fascia can be seen (and picked off) and the pulp in its circularly arranged sections can be observed. In order for wedges of the orange to be eaten, the individual compartments, each divided by investing layers of fascia, must be separated. Fascial planes, the potential space between two layers of connective tissue, allow for this division.

Unfortunately, cadaver-based anatomy protocols start by "clearing" or "cleaning" the connective tissue covering from structures for visualization. Disrupting the fascia means losing the story that the connective tissue surrounding muscle is not an isolated or independent entity, rather it is a continuous substance throughout the body plan. There is a reason why every unit studied in medicine involves fascia (or the removal of it). Fascia is pervasive, persistent, and ever present, no matter what region the students are observing. In fact, the continuity of fascia throughout the body can be attributed to its embryologic origin in the mesoderm (van der Wal, 2009). Teaching the role of dense connective tissue in compartmentalizing muscles and their neurovascular bundles is a wonderful way to familiarize students with fascia and pattern recognition in gross anatomy. Fascia provides clinical educators with opportunities to discuss planes and clefts for surgical access, muscle group actions, and pathologies such as compartment syndrome. Clinical applications of aponeuroses and contracture via fasciitis, Dupuytren's contracture, are all occasions for reflecting on the importance of fascia in the medical field. Loose and dense fasciae in the thoracic cavity define why some diseases may occupy the thoracic cavity but not the plural cavity (Moore et al., 2015).

Reflections of peritoneum and pathological adhesions in the greater sac discovered in the gross lab provide instructors with teachable moments to discuss the presence of collagen and its ability to both limit mobility and increase mobility and manipulate the morphology of the surrounding tissue. An additional teaching example would be the fascial compartments of the neck, which are defined by columns of connective tissue that delineate areas and determine the spread of infection. Consider choosing fascia to foster discussions on life stages (embryo to elderly), activity levels (sedentary to professional athlete), medical procedures or techniques (surgical to surface massage), and alternative therapeutic options that future patients may wish to consider.

Histology

There are four tissue types responsible for the tremendous number of body structures and body functions. One of these tissue types is connective tissue. Discussion of the microscopic anatomy of connective tissue proper provides educators with many opportunities for dialog on the fascia continuum. Basic sciences unfortunately categorize discrete types of connective tissue despite the fact that there are no distinct starting and stopping points as one travels from loose connective tissue to a densely arranged system throughout the body. Therefore, it is clinically relevant to point out the continuity of fascia as a whole entity. When we examine the components of fascia, we observe that this tissue is a network of fibers (mostly collagen and/or elastic microfibrils), which laid the three-dimensional scaffold that maintains the structural integrity of organs (Benjamin, 2009). Specific fibers organized for strength, recoil, absorption, or rigidity are placed within the ground substance that includes hyaluronan and the water it attracts (interstitial fluid). The distribution of cell types within this tissue modifies the proteins and ultimately the function of the extracellular matrix (ECM): the building block of fascia. By manipulating the three main fascial ingredients: fibers (collagen, elastin), ground substance (glycosaminoglycans, hyaluronic acid, proteoglycans), and cells (residential macrophages to transient neutrophils), you vary the connective tissue outcome. The histological framework of the ECM and the specific cells that reside in or pass through the scaffolding work together to form a bidirectional mode of cell–matrix communication is essential for the maintenance of homeostasis and metabolism. While we may teach fascial histology as having distinct two-dimensional boundaries, it should be stressed that the borders between our categories are somewhat arbitrary when more appropriately viewed as an extensive three-dimensional network. One can widely observe loose and dense fibrous connective tissues in any region of the gross form, including adipose tissue, adventitia, neurovascular sheaths, aponeuroses, deep and superficial fasciae, epineurium, membranes, joint capsules, ligaments, meninges, myofascial expansions, periostea, retinacula, septa, and tendons.

Consider utilizing gross images of fascia in didactic learning events or online modules to help students link the common (macro) to the less common (micro) discipline of histology. For example, consider discussions that relate the aging process to the fascial structure and function (distribution of adipose, skin elasticity, and intervertebral disc fluidity).

Biochemistry

Fascia also serves as a means of providing students with a contextual environment for discussing the intricacies of signal transduction pathways and biochemical cycles. Without the ECM and the addition of cells to form fascia, we lose the scaffolding for our physiological switchboard operators critical in the day-to-day monitoring of homeostasis. Effective learning events in biochemistry utilize fascia as a multifunctional tissue that can influence multiple biochemical and mechanical processes simultaneously. Numerous interactions, which vary in the chemical and mechanical composition of the extracellular microenvironment, happen simultaneously in the fascia. For example, cell–cell signaling via numerous receptors results in a variety of mechanisms of activation and signal transmission as well as subcellular localization and phosphorylation (Mitra et al., 2005).

The continuum of fascia throughout the body also allows it to serve as a body-wide mechanosensitive signaling system (Langevin and Huijing, 2009). Cells in living tissue are anchored to the ECM through focal adhesions. At these sites, there are clusters of transmembrane receptors, known as integrins, that bind to the ECM molecules on the outside of cells to secure 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. Cells need to be in their mechanical "just right place," like in the story of *Goldilocks and the Three Bears*, to function. An overly crowded environment can produce cell suicide; an overly stretched environment can stimulate cell reproduction; and it is different for different cells. For example, a low load (gentle pressure) applied slowly will allow the viscoelastic medium (fascia) to elongate. 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 (Ingber, 2008; Adstrum, 2017).

Presenting the histological organization of fascia with biochemistry can be an excellent means of introducing students to cell signaling because it provides them with a familiar perspective for learning the complex signaling that occurs between any cell and its environment. Biochemical pathways can be equated to a wide range of cell "languages"; the fascia then provides the specific environment for language translation or acts as a barrier to dialects.

Genetics

From the moment of conception, the fascial environment within the embryo is critical to its proper development. The ECM plays an essential role in the development of skeletal musculature in the embryo (Mammoto and Ingber, 2010). Furthermore, manual massage applied to the surface of a leg can be traced to the effects on underlying cells, with changes in the nucleus and DNA transcription within minutes of the applied pressure (Crane et al., 2012).

The living cell is a mechanical structure with a force balance between compression-bearing microtubules and tension-bearing bundles of actomyosin filaments. The cells are anchored to the ECM by clusters of integrin receptors that connect extracellular proteins to intracellular actin-associated molecules. These receptors also serve to sense physical forces outside the cell and transmit that information via mechanical connections to the nucleus and cytoplasm. This cytoskeleton provides both mechanical structure and direction to biochemical reactions within the cell. The cell can thus convert external mechanical signals into internal biochemical reactions (Mammoto and Ingber, 2010). The physiological effects of physical forces have long been recognized by clinicians, for example, skin elasticity and aging, bone compression and formation, shear stress, and vascular remodeling. With the deciphering of the human genome, a comprehensive theory that incorporates three-dimensional geometry and physical forces to explain the folding, assembly, and function of biosynthesized molecules remains to be developed. A study by Crane et al. (2012) revealed that manual massage after exercise activated force-conducting pathways to the nucleus leading to subsequent, within hours, changes in gene transcription.

Fascia is also a foundation for the discussion of oncology because it provides students an environment for the breakdown of lines of communication controlling cell proliferation, specialization, interaction, and movement that are under the direction of each cell's DNA. Consider holding discussions on primary and secondary tumor growth with regard to environmentally specific changes to ECM phenotypes. Modifications to genetic coding can influence protein production (quantity and quality) and signaling that in turn alter the molecules and proteins that accumulate in the surrounding ECM (Miao et al., 2000). Utilizing neoplastic growth is one example of how fascia provides students with a contextual framework for genetic regulation of cellular roles and the ECM, both of which can be of clinical significance.

Physiology

Physiology is another arena well equipped to support fascial deliberations. We understand that connective tissue provides a structural framework for cell and tissue growth as it develops around the structures of the body, continuously adapting and transmitting mechanical and chemical signals to differentiate tissues (Ingber, 2008). In a broad sense, fascia allows organ systems to be described as an interconnected network that acclimates its fiber arrangement, length, and density according to local, cellular, and tensional demands, as well as chemical cues.

Fascia can also be the foundation when instructing students about migratory cells and why there are concentration gradients and haptotactic migration. During organogenesis, the ECM also plays an important role in directing developmental traffic. Developmental properties connect well to fascia as it is degraded by invasive cells. During disease progression as well as in development, fascia can be called upon to help students understand growth factors, receptors, and ligands. Essential concepts linked to fascia are topics such as the distribution of ECM-bound molecules, feedback loops, and cross talk between growth factor receptors and the ECM. What some students may not know is that fascia allows for spatial regulation of protein factors as well the sequestering and storage of proteins, which aid the body in mediating a response (Adstrum, 2017). The release of these factors in the presence of the most appropriate cell-mediated force or communication happens within fascia. Coming a full circle, we can return to the mechanical properties of the fascia when discussing cell differentiation and the cellular response to mechanical signals and cues, which in turn activate the intracellular signaling through interaction with cell surface receptors, the cytoskeletal machinery, and the nucleus (Fletcher and Mullins, 2010).

The interpretation of the physiological effects of fluid gradients is yet another topic that actively involves fascia. Loose connective tissue harbors the vast majority of the 15 l of interstitial fluid in our body (Reed and Rubina, 2010; Reed et al., 2010). This flows through a connective tissue matrix that contains cells such as fibroblasts, tumor cells, immune cells, and adipocytes. Interstitial fluid flow can have important effects on tissue morphogenesis, cell migration, differentiation, and remodeling. For example, fibroblasts embedded in the ECM align themselves perpendicular to the direction of fluid flow. Variations in water, ions, and other substances can also alter the biomechanical properties of loose connective tissue. The slightest change in fluid flow can alter the shear stress on a cell surface, thus altering cell physiology. 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 toward lymphatic capillaries (Rutkowski and Swartz, 2007).

Knowing that fascia is not a static structure, but in fact a multifunctional and dynamic tissue can help students understand the complexity of physiological responses to our body's needs (i.e., pain or discomfort). Tensegrity structures can serve as models for water displacement and for reactions to tension, or how compression in one region can be observed affecting neighboring structures (Ingber, 2008). Fascia also presents educators a framework for teaching communication cascades and feedback loops that can lead to local or distant modifications in cell function. Learning that cells are not isolated but connected via an intricate web of fascia (ECM and neighboring cells) encourages students to see that minute changes within a physiological response can ultimately be observed as a patient's chief concern or side effect of treatment.

Neurology

Fascial coverings of nerves and nerve fascicles are richly innervated and populated with plexuses of nociceptors (Bove, 2008). Abundant free and encapsulated nerve endings have been observed in the thoracolumbar fascia, the bicipital aponeurosis, and various retinacula (Benjamin, 2009). The thoracolumbar fascia is densely innervated with different nerve endings distributed in different facial layers. These sensory thoracolumbar fascia fibers provide input to lumbar dorsal horn neurons, perhaps contributing to the source of lower back pain (Tesarz et al., 2011). Similarly, nociceptive fibers originate from regions of crural (deep) fascia (Bhattacharya et al., 2010; Taguchi et al., 2013), and fascial pain endings can be sensitized by local injections of nerve growth factors (Deising et al., 2012). 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 (Tesarz et al., 2011). 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 venules, 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 (Gillies, 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 (van der Wal, 2009). A specific pattern of proprioceptor activation occurs when there is fascial tension, and it is directly associated with the deep fascial relationship to muscles (Benjamin, 2009). Fascia research can help us understand the aspects of musculoskeletal problems such as myofascial trigger points, low back pain, and fibromyalgia.

Musculoskeletal

Our "fascial system" consists of a body-wide tensional network of connective tissue (Zügel et al., 2018). There exists a continuity of fibrils from the ECM through the integrin receptor and the cell membrane to the nucleus. It is a useful concept to think of the body as a fascial network with connections to muscles and bones, rather than the more traditional view of a muscular system with fascial connections (Willard et al., 2012).

The deep fascia is not just a tough barrier structure of collagen and elastin, but is a metabolically active vascular layer that provides gliding and protective functions (Bhattacharya et al., 2010). Deep fascia has parallel longitudinal collagen bundles and rudimentary elastic laminae, giving it both high tensile strength and elasticity. At the junction between the deep fascia and the muscle, with special secretory cells, the fascia is able to maintain a lubricating layer of hyaluronic acid (Stecco et al., 2018). However, when the epimysium is disrupted, the overlying fascia does not remain distinct and does not create a gliding layer over the muscles (McCombe et al., 2001).

The intramuscular ECM 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 fiber bundles. The endomysium is a continuous network of connective tissue that covers individual muscle fibers with small fascial fibers extending to connect to the cell membrane itself (Passerieux et al., 2006). Gillies and Lieber (2011) pointed out that while these may seem distinct in two-dimensional sections, the borders between these tissues are somewhat arbitrary when viewed as an extensive three-dimensional network, with connective tissue fibers extending both along and across muscle fibers. The middle layers of perimysium appear to be continuous with the tendon attachments and the periosteum. Moreover, this intramuscular architecture is not fixed, but demonstrates increased collagen content and decreased organization after a period of immobilization of an extremity (Järvinen et al., 2002). During exercise and muscle fiber circumferential growth, research demonstrates an increased turnover of the investing connective tissue (Purslow et al., 2012).

Fascia and Therapies

Movement and stretching such as yoga, Pilates, physical therapy, and osteopathic manipulative medicine therapy can help cells regain their proper environmental tension by relieving fascia-related pressure or strain, resulting in better body function. Manual therapy techniques treat the fascial layers by altering density, tonus, viscosity, and the arrangement of fascia. Manual stimulation of sensory nerve endings may lead to changes in muscle tone (Willard et al., 2012).

Therapies designed to locally increase edema such as Chinese cupping may increase the adaptability of the fluid flow adjustment systems by temporarily increasing fluid flow. Therapies designed to reduce lymphedema must consider the tissue changes that take place with prolonged decrease in interstitial flow, including the increased tissue compliance or "overstretching" of the interstitial matrix. Organs must be viewed in the context of the surrounding connective tissues and distant blood and lymphatic fluid flow, and specific organ pathology cannot be fully understood or treated without taking those tissues into account.

To demonstrate viscosity and "fluidity flow" that occur with the manipulation of fascia and muscles, one can use a raw egg cracked open on a plate. Compare and contrast the dynamic properties of the egg white versus the egg yolk encased in a thin membrane by applying gentle pressure to each.

CONCLUSION

"I know of no part of the body that equals the fascia as a hunting-ground. I believe that more rich golden thoughts will appear to the mind's eye as the study of the fascia is pursued than of any other division of the body. (…) No part [of the body] can be dispensed with" (Still, 1899).

Fascia not only connects the body but can serve as a bridge across many aspects of healthcare education. Since the properties of fascia connect biological systems, this topic may easily be embedded in our health curricula. Fascia provides us with a means with which to treat the whole body. The complexity of fascia allows one to travel from the macroscopic world (fascial planes) to the microscopic world (ECM and cell membranes) offering educators an endless number of learning avenues. For many aliments such as short-term injuries, long-term pain, chronic physical disorders, and even stress-induced tension, fascia should be looked upon as a key contributor.

"In every view we take of the fascia a wonder appears. The part the fascia takes in life and death gives us one of the greatest problems to solve. (…) By its action we live and by its failure we die" (Still, 1899). Therefore, as long as one of the goals of health professionals remains to assist their patient in returning to a state of homeostasis or balanced well-being, fascia should have a permanent home in medical curricula.

ACKNOWLEDGMENTS

I would like to thank Dr. Thomas Findley and Kara Schabacker for being excellent copresenters and sharing their love of fascia with me and with our international audience in 2018. I also wish to thank Dr. Zadok Ruben for his fascia enthusiasm. I am grateful that our career paths crossed.

REFERENCES

Adstrum S, Hedley G, Schleip R, Stecco C, Yucesoy C. 2017. Defining the fascial system. J Bodyw Mov Ther 21:173–177.

Benjamin M. 2009. The fascia of the limbs and Back - a review. J Anat 214:1–18.

Bhattacharya V, Barooah P, Nag T, Chaudhuri G, Bhattacharya S. 2010. Detail microscopic analysis of deep fascia of lower limb and its surgical implication. Indian J Plast Surg 43:135–140.
Bove GM. 2008. Epi-perineurial anatomy, innervation, and axonal nociceptive mechanisms. J Bodyw Mov Ther 12:185–190.
Crane J, Ogborn D, Cupido C, Melov S, Hubbard A, Bourgeois J, Tarnopolsky MA. 2012. Massage therapy attenuates inflammatory signaling after exercise-induced muscle damage. Sci Transl Med 4:113.
Deising S, Weinkauf B, Blunk J, Obreja O, Schmelz M, Rukwied R. 2012. NGF-evoked sensitization of muscle fascia nociceptors in humans. Pain 153:1673–1679.
Ingber D. 2008. Tensegrity and mechanotransduction. J Bodyw Mov Ther 12:198–200.
Fletcher D, Mullins R. 2010. Cell mechanics and the cytoskeleton. Nature 463:485–492.
Findley T, Chaudhry H, Dhar S. 2015. Transmission of muscle force to fascia during excerise. J Bodyw Mov Ther 19:119–123.
Gillies AR, Lieber RL. 2011. Structure and function of the skeletal muscle extracellular matrix. Muscle Nerve 44:318–331.
Järvinen TA, Józsa L, Kannus P, Järvinen TL, Järvinen M. 2002. Organization and distribution of intramuscular connective tissue in normal and immobilized skeletal muscles. An immunohistochemical, polarization and scanning electron microscopic study. J Muscle Res Cell M 23:245–254.
Langevin HM. 2006. Connective tissue: a body-wide signaling network? Med Hypotheses 66:1074–1077.
Langevin HM, Huijing PA. 2009. Communicating about fascia: history, pitfalls, and recommendations. IJTMB 2:3–8.
Mammoto T, Ingber D. 2010. Mechanical control of tissue and organ development. Development 137:1407–1420.
McCombe D, Brown T, Slavin J, Morrison WA. 2001. The histochemical structure of the deep fascia and its structural response to surgery. J Hand Surg Eur 26:89–97.
Miao H, Burnett E, Kinch M, Simon E, Wang B. 2000. Activation of EphA2 kinase suppresses integrin function and causes focal-adhesion-kinase dephosphorylation. Nat Cell Biol 21:62–69.
Mitra S, Hanson D, Schlaepfer D. 2005. Focal adhesion kinase: in command and control of cell motility. Nat Rev Mol 6: 56–68.
Moore K, Dalley A, Agur A. 2015. Clinically Oriented Anatomy. Baltimore: Lippincott Williams and Wilkins. p 744–793.
Passerieux E, Rossignol R, Chopard A, Carnino A, Marini JF, Letellier T. 2006. Structural organization of the perimysium in bovine skeletal muscle: Junctional plates and associated intracellular subdomains. J Struct Biol 154:206–216.
Purslow PP, Archile-Contreras AC, Cha MC. 2012. Meat science and muscle biology symposium: manipulating meat tenderness by increasing the turnover of intramuscular connective tissue. J. Anim Sci 90:950–959.
Reed RK, Liden A, Rubin K. 2010. Edema and fluid dynamics in connective tissue remodeling. J Mol Cell Cardiol 48:518–523.
Reed RK, Rubin K. 2010. Transcapillary exchange: role and importance of the interstitial fluid pressure and the extracellular matrix. Cardiovasc Res 87:211–217.
Rutkowski JM, Swartz MA. 2007. A driving force for change: interstitial flow as a morphoregulator. Trends Cell Biol 17:44–50.
Stecco C, Fede C, Macchi V, Porzionato A, Lucia P, Biz C, Stern R, De Caro R. 2018. The fasciacytes: a new cell devoted to fascial gliding regulation. Clin Anat 31:667–676.
Still AT. 1899. Philosophy of Osteopathy. Kirksville, MO: Published by the author.
Taguchi T, Yasui M, Kubo A, Abe M, Kiyama H, Yamanaka A. 2013. Nociception originating from the crural fascia in rats. Pain 154: 1103–1114.
Tesarz J, Hoheisel U, Wiedenhofer B, Mense S. 2011. Sensory innervation of the thoracolumbar fascia in rats and humans. Neuroscience 194:302–308.
van der Wal JC. 2009. The architecture of the connective tissue in the musculoskeletal system - an often-overlooked contributor to proprioception in the Locomotor apparatus. Int J Ther Massage Bodywork 4:9–23.
Willard F, Fossum S. 2012. The fascial system of the body. In: Chila A, editor. Foundations of Osteopathic Medicine. Baltimore: Lippincott Williams and Wilkins. p 74–92.
Zügel M, Maganaris C, Wilke J, Jurkat-Rott K, Klingler W, Wearing SC, Findley T, Barbe MF, Steinacker JM, Vleeming A, Bloch W, Schleip R, Hodges PW. 2018. Fascial tissue research in sports medicine: from molecules to tissue adaptation, injury and diagnostics: consensus statement. Br J Sports Med 52:1497–1506.