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• Commentary

The indeterminable resilience of the fascial system

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ABSTRACT

The most recent information on fascial tissue indicates that there are not fascial layers, but polyhedral microvacuoles of connective tissue, which connect the body systems and, by hosting specialized cells, permit several functions, such as motor, nervous, vascular and visceral. These microvacuoles (a repetition of polyhedral units of connective fibrils) under internal or external tension change shape and can manage the movement variations, regulating different body functions and ensuring the maintenance of efficiency of the body systems. Their plasticity is based on perfect functional chaos: it is not possible to determine the motion vectors of the different fibrils, which differ in behavior and orientation; this strategy confers to the fascial continuum the maximum level of adaptability in response to the changing internal and external conditions of the cell. The present commentary deals with this concept, providing clinical examples of different disease patterns, providing contrary examples in which this adaptability does not occur, and lastly suggesting considerations for the approach to manipulative therapy of the fascial tissue. The fascial continuum is like a flock of birds flying together without a predetermined logic and maintaining their individuality at the same time.

Keywords: fascia; osteopathic; manual therapy; fibroblast; fascial continuum

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1 Introduction

From a macro-anatomic perspective, the fascial tissue is equally distributed throughout the entire body, creating various layers at different depths and forming a three-dimensional metabolic and mechanical matrix.[1,2]

Usually, we can distinguish four fascial planes: the superficial fascia, the axial/appendicular fascia, the meningeal fascia and the visceral fascia. The superficial or pannicular fascia is absent in the orifices such as the eye sockets, nasal and oral passages and aboral apertures; it is composed of irregularly organized connective tissue, with

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varying thickness depending on location in the body and presence of fat.[3] The axial fascia, investing fascia or deep fascia is peripherally fused with the previous layer, and extends in depth through the body, surrounding the contractile areas, the vessels and the nerves. This classification includes the epimysium, the periosteum, the tissue that covers the tendons and ligaments, as well as joint capsules.[3] The axial layer is formed by packets of irregularly organized collagen fibrils, and runs along the front and back of the spine, like two parallel rails.[3] Each muscle related to the spinal column and the upper and lower limbs is covered by the pannicular fascia, whilst below there is axial fascia.[3] The meningeal fascia surrounds the central nervous system, ending with the epineurium, which covers the peripheral nerves.[3,4] The visceral fascia extends from the cranial base to the pelvic cavity, covering all the organs and guiding the neurovascular and lymphatic packets towards the organs; the density of this fascia varies depending on its location in the body.[3]

From a microsurgical point of view, by using *in vivo* endoscopic images representing magnifications of anatomical areas, the fascial system can be understood not as an ensemble of layers, but as many inseparable connective units, or a fascial continuum, not permitting the identification of different layers.[5] In studying the organization of connective from the skin to the bone, we can see that the collagen fibrils form a network without separate layers; the same structures can be found from the top to the bottom of the fascia, and the so-called layers are distinguishable only by the density of their fibrils.[5] The same connective structures compose blood and lymphatic vessels, bones, muscles and tendons, as well as nerves. It is the organization of the network of structures that determine the function.[5] The connective fibrils form a repetition of polyhedral units called microvacuoles; these volumes are created between the fibrillar intersections, and are always different in their shapes.[5] The microvacuoles may contain cells (fibroblasts largely constitute the microvacuoles), creating the structure (viscera, muscles, nerves and vessels), thus determining functions; this organization can be observed in the whole body, from the epidermis to the cell nuclei.[5]

The microvacuoles have a diameter ranging from a few microns up to 200 nm, with their size probably depending on the cells that they incorporate and/or on the body area where they are found.[5] The fibrils vary in size between 5 nm and 70 nm in diameter, reaching a length of 10–100 nm.[5] These fibrils are comprised of about 70% collagen types I, III and IV, and about 20% elastin, with around 4% lipids.[5] The microvacuoles are rich in water, due to the hydrophilic properties of the lipids and in particular of proteoglycans (approximately 72%).[5] The core of these molecules is a protein with one or more covalent bonds with polysaccharides (glycosaminoglycans, GAG); the negative charge of GAGs attracts water molecules, facilitating their passage through the membrane of the microvacuoles, and ensuring hydration.[5] This hydration maintains constant pressure within the volumes, allowing them to adapt to the changing internal and external pressures of cells and systems, such as movement or spontaneous variations in blood pressure.[5]

The fibroblasts are the foundation of the fascial continuum.[2] The fibroblasts adapt according to the metabolic and mechanical stimuli present; they allow real-time communication among distant areas of the whole body.[2] Thanks to the fibroblasts, connective fibrils communicate from a mechanical and metabolic point of view.[2] Between two fibroblasts there are gap junctions, made up of two cells known as connexons, which create continuity. They consist of six identical (homomeric) or different (heteromeric) proteins, called connexins.[2] These junctional structures facilitate the conveyance of mechanical information, as well as of small molecules and electrical activity. Communication is possible with distant cells, but not necessarily with those close to one another. Recent research has revealed the existence of nanotube tunnels that differ from the connexons because they allow the continuation of the membrane even when it is far from the original cell or has an irregular direction, and can reach many centimeters in length.[2] These nanotubes are characterized by a contractile structure composed of F-actin and VA myosin. This characteristic is thought to facilitate a rapid transmission of metabolic and electrical information, as the communication between cells takes place just in a few minutes; these connections do not appear to be permanent, but transient.[2]

Other cellular structures recently discovered in the fascial continuum, in particular in the fascia lata of the lower limb, are telocytes. These can be found side by side with fibroblasts and are also able to communicate with distant cell bodies through their prolongations (telopodes), probably, to allow better propagation of the metabolic information.[6]

The fascial continuum can be plausibly considered to be a memory organ, because it not only registers the functions of the structures it surrounds and connects, but also memorizes any function or information arriving and departing from the same structures. The connective tissues remember the morphological variations they have undergone, and this probably influences the behavior expressed by the tissues.[2] Spider web is very reminiscent of the perfect and chaotic organization of the fascial system that can catch the water (Figure 1).

Figure 1 A spider web with morning dew

2 Fascial disorder

The connective tissue that constitutes the fascia is anisotropic, i.e., a condition where a measured property is different in different directions; this allows maximum adaptation to deal with the exogenous and endogenous demands of the body.[5] The fascial anisotropy reflects the concept of biotensegrity, based on the presence of discontinuous compression elements (bones) that balance the stress generated or received by continuous tension elements (muscle and fascia).[1,7] The biotensegrity and anisotropy allow the fascial continuum to continuously and constantly adapt, always making it different instant by instant.[3] Spider web recalls the concept of biotensegrity: based on the presence of discontinuous compression elements (small branches and leaves) that balance the stress generated or received by continuous tension elements (external factors such as wind or rain) (Figure 2).

Figure 2 A spider web connecting small branches and leaves

The connective fibrils constituting the microvacuoles are chaotically arranged, without any predetermined scheme; the fibrils can move independently, sliding one over another at different speeds.[8] Under tension (internal or external to the microvacuoles and/or cells), these connective polyhedra change shape. The fibrils are stretched, with the number of fibrils involved proportionally increasing with the increase in tension.[5,9] Neighboring fibrils do not have identical responses, and may have different responses to the same stimulus intensity.[5,8] The load absorbed and transmitted by the fibrils is not linear. The lose organization of the fibrils allows the structure to absorb applied forces; as individual fibrils are stretched, others are recruited to absorb and transmit the load. The ability of any one fibril to absorb or transmit load is highly dependent on its position realative to the direction of the load.[5,8] To visualize how microvacuoles behave, we can consider a flock of birds flying together while maintaining their own identity the chaotic order in the perfection of the movement (Figure 3).

Figure 3 A flock of birds flying together while maintaining their own identity

Each fibrils can stretch by around 15%–20%. Furthermore, the fibrils can move even within the microvacuoles.[5] This fractal organization, with its connotations of quantum physics concepts, allows the maximum ability to absorb and transmit tensions.[5] The change in the shape of the microvacuoles simultaneously determines the change of the shape of the cells that they may confine. This is known as mechanotransduction. The deformation of the cell causes a biochemical response, allowing the cells to develop.[5,10] The ability to properly dissipate changes in tension, while maintaining the position and the shape of more complex structures (from the tendon to the liver, etc.), ensures optimal body functions.[7,9]

The geometric organization of the fibrils reflects the fractal nature of the fascial continuum, and the infinite variability of structures in a nonlinear and nondeterministic manner.[11]

Fascial non-organization leads to entropy, i.e., an equilibrium of disorder. Entropy is defined in quantum mechanics as the measure of disorder in a system.[12] The entropy consists of the possible different arrangements of the molecular levels (cells) and of how, amongst the different probabilities, the actual system presents macroscopically.[13] A low entropy of a system or a high entropy of the system, will determine an increase or a reduction of its organization.[13]

We do not currently have any data on the possible evolution of the fascial continuum before a disease occurs.

3 Fascial order and manual therapy

The fibrils transmit tension directly to the nucleus of various cells, due to the integrin-extracellular matrix complex. From the skin, a message can reach the cellular DNA of the deep structures.[5] Here we will give a simple example using classical (macro) anatomy terms. The connective organization of the epidermis (stratum corneum, granulosum, spinosum and basale) relates directly to the dermis (papillary and reticular), and hypodermis with several thin layers (superficial, intermediate and deep), through connective fibrils with different orientation.[5] Within or beneath the hypodermis, there is the so-called superficial fascia, and below that, the areolar fascia and then the deep fascia.[5] The latter is connected to the various subdivisions of the muscle, from the epimysium to the endomysium. The fibrils of the endomysium are connected to the sarcolemma through the extracellular matrix by way of various connective and protein structures (including laminin, collagen type IV and integrins). Certain proteins of the sarcolemma connect in turn the membrane inside the fibrils (dystroglicans versus dystrophins).[14] The dystrophins are connected to costameres (perpendicular protein structures, consisting of protein filaments), which bind to proteins of the nuclear membrane, up to DNA which bind to other proteins.[12,15] In reality, the various layers and systems are all connected, without loss of continuity, in which the functional chaos of the fascial continuum allows the maximum efficiency of all systems. Fibrils in a nonpredetermined organization are able to better manage mechanical information.

Fascial anisotropy in all its micro- and macrocellular constituents guarantees the system maximum efficiency.[16,17] This means that to work best, the fascial continuum must not be organized. Indeed, when subjected to increased organization, pathological conditions can appear.[3,18–20] If the flexibility of the microvacuoles is lost, a thickening of the fascial tissue can form (fibrosis or densification); these changes prevent the different fascial layers from sliding and adapting, leading to pain and pathological conditions.[2,3,18]

The literature is full of clinical examples that demonstrate how an alteration of the fascial organization can cause disease: the loss of the chaotic disorganization described above will cause dysfunction.

Changes in skin tone due to aging reflect a loss of the bond between water and the collagen fibrils, and affect the orientation of the fibrils, making the skin less responsive to changes in tension; the number of connective structures is maintained, but their hydrophilic ability is reduced.[21] This inevitably leads to decreased entropy of the fascial continuum.

The myocardial fibrils are oriented in multiple directions, have anisotropic properties and disperse most of the contractile forces of the heart's work.[22,23] In the case of myocardial infarction, the necrotic tissue is replaced by new fibrillar connective structures, differing from the original ones in their percentage of myofibroblasts and their orientations. The necrotic area is transformed into a fixed mechanical organization, limiting the flexibility of the heart contractile activity.[24,25]

The stenosis of a coronary vessel, due to the sudden rupture of a plaque, will induce a cardiac ischemic process. One of the probable causes of this event, is a change in the physiological elasticity of the vessel, resulting in its inability to properly handle stress and strain from the passage of blood, with a decreased capacity of the vessel to handle shear stress.[26] Most likely this altered elasticity is due to changes in the orientation of collagen fibrils that constitute the vessel, making it more rigid.[26]

Cancer metastases reorganize their connective environment, allowing cancer cells to move more easily.[27] The functional disorganization of the fascial continuum can be protective against metastatic proliferation. The fibrosis and fascial organization that is found in muscles of patients undergoing chemotherapy produces pain and decreased voluntary movement, mimicking peripheral neuropathy.[28,29]

Another example of the relationship between the fascial continuum and the body system is the optic nerve. It has been shown that the change in orientation of collagen fibrils in the optic nerve, especially with ageing, is one of the possible causes of neuropathic glaucoma.[30]

Bone cells have a close relationship with collagen fibrils inside and outside of the bone (e.g., fibrils wrap osteoblasts and bone and collagen layers alternate). The osteocytes reside on the bone surface. Through gap junctions osteocyte proteins connect with the environment external to the bone; at the same time they create gaps and canals into the interior of the bone.[31] According to recent research, the osteocytes receive water from the connective tissue through the canals and bone gaps, producing tension (fluid shear stress); this tension creates the mechanotransductive stimulus for bone production.[31] The orientation of collagen is critical for the occurrence of this event, and the orientation of collagen fibrils is also crucial for the correct distribution of loads in the bone.[31] Altering the bone cytoarchitecture, and certain patterns of collagen fibrils distribution, leads to bone disease.[32]

The fibrosis (organs or skeletal muscle) associated with many chronic diseases often takes many years to became manifest and only then does it significantly affect tissue function. If the wound healing response is dysregulated, the tissue repair process may devolve into fibrosis, with increase of collagen tissue in a pathological pattern. The ability of cells to feel or sense the microenvironment is lacking.[33]

The cervix of the uterus is crucial for proper pregnancy. It is rich in collagen, with only 15% muscle fibrils; stiffening of the structure, from various disease states, can cause serious complications.[34] It has been shown that the most important causes of cervical dysfunction is not the loss of connective tissue, but a reorganization which results in decreased elasticity of the structure.

The presence of the muscle connective system allows the consistency of the contractile cells and their proper function (strength and biomechanics).[35] Hospitalization, or a prolonged period of muscular inactivity can lead to the loss of organization and orientation of collagen fibrils, resulting in an altered use of muscular districts.[35] There is substantial increase in the number of perpendicularly oriented collagen fibrils with contacts to two adjacent muscle fibrils in the endomysium; in the perimysium changes are similar. This changes in the intramuscular connective tissue are likely to contribute to the deteriorated function and biomechanical properties of the immobilized skeletal muscle. The muscle strength depends on how the connective fibrils are aligned, thus, altered orientation can result in altered function of the fibrils and decreased performance of the muscle.[34]

When the metabolic environment is altered mechanically, for example in the presence of inflammation, the microvacuoles change their size, becoming megavacuoles, where the fibrils tend to retract, to lose their hydrophilic properties and to become more swollen, with limited resiliency.[5] These changes will make the system more fragile, breaking the fibrils and resulting in further creation of megavacuoles.[5] These reactions are typical of joint inflammation.[5]

A skin lesion, trauma or surgery will cause scarring and adhesions at different levels.[36] In these situations, the connective system is completely changed and the flexibility of tissues is lost.[5] Symptoms and signs related to scars and adhesions have been exhaustively described in a previous article.[36]

Chronic heart failure is a progressive, debilitating disease, defined as the inability of the heart to meet the demands of oxygen from the peripheral area. This patient population often has a low quality of life, and the majority of patients have a short life expectancy, with a strong chance of dying within 5 years of diagnosis.[1] If altered, the fascial continuum generates a symptomatology that deteriorates the health condition of the patient. Recent study has shown that the nociceptive afferents from the fascial system can cause symptoms such as fatigue and muscle pain: dysfunction in the fascia sends nonphysiological information to the central nervous system, with a pathological return efferent.[1]

The organization of collagen fibrils positively influences lymphatic flow (transinterstitial fluid movement), driving the lymph in the correct direction. If the fascia's entropy is decreased, lymphatic drainage could be compromised, affecting the proper function of the immune system.[20] The fascial continuum supports the venous system, influencing the venous caliber and the passage of blood. The decline of the flexibility of the fibrils can cause varicose veins.[20] The creation of a nonphysiological pattern sets the conditions for the occurrence of disease.[20,37–39]

Further studies are needed to understand the mechanisms that underlie these diseases.

The fascial continuum is a focus of treatment for practitioners such as osteopaths, manual therapists and physiotherapists. When a patient seeks treatment from a manual practitioner, a problem has already arisen, which may be localized or more diffuse within the fascial. At this point, fascial entropy has been reduced, as well as the possibility of adaptation.

The literature shows that the application of manipulative therapy, with the intention of improving the fascial continuum and symptoms, is effective, within certain limits of the pathology and the patient.[5]

Some *in vitro* studies have assessed the behavior of fibroblasts subjected to different forces, imitating tension usually applied in some manual techniques for the treatment of the fascia.[40,41] The fibroblasts responded in different ways, changing their shape, with autocrine and paracrine synthesis of biological substances which are fundamental for the proper function of the cells.[40,41] Activation of fibroblasts stimulates secretions of necessary proinflammatory cytokines and extracellular matrix proteins, enhancing proliferation and migration, which when combined contribute to promoting tissue and cell repair.

There are mathematical models that try to understand how the fascial continuum behaves in the response to technical manipulation. They try to theoretically assess how the pressure manually applied to the skin (in tangential way, perpendicular way and through vibrations), works and how much strength and time are needed to stimulate the fascial continuum from the surface to deepest part.[42–44] These studies took into consideration only certain areas of the body, such as the nasal fascia, the plantar fascia and the fascia lata.

When a trauma occurs, the tissue loses its anisotropy; the fibrils are reorganized with more systematic orientations, and depending on the extent of the trauma, this will lead to mild or serious consequences.[45]

Currently, we do not know what happens to the fascial continuum during the application of manual techniques; literature suggests many advantages of performing manual treatments, but we do not know which is the best, promoting the most natural conditions of the fascia. The difficulty also lies in the fact that different areas of the body, with different functions, have a different fibrillar connective behavior.

The practitioner performing manipulative therapy should be aware that the real fascial response to the stresses induced during the treatment is not completely known; probably a good practitioner should not use only one therapeutic manipulative technique, in order to avoid affecting the behavior of microvacuoles. Research should make greater efforts to investigate the response of the fascial fibrils in the presence of manipulative therapy, in order to guide practitioners in their practice.

4 Conclusion

The resilience of the fascial continuum is indeterminable, conferring to the various systems the highest adaptability to internal and external stimuli; the organization of microvacuoles manages and transmits the forces through an entropic mechanism. When a dysfunction or a disorder is present, this entropic system is altered, resulting in a decreased ability to adapt and to protect the body's functional organization.

Unfortunately, we do not know yet what happens to the fascial continuum during manual stresses, and we do not completely know which therapeutic procedure should be used to take advantage of the fractal structure of the fascia.

This commentary is based on a hypothesis rather than clinical evidence or clinical theories.

5 Competing interests

The authors report no conflicts of interest in this work.

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