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Review

Unity, Continuity, Structure, and Function. The Ongoing Search for a Deeper Understanding of the Many Roles Attributed to Fascia in the Living Human Body - An Osteopathic Perspective

Colin Armstrong *

Osteopathic Centre, 1732 Voie Aurelienne, 13450 Grans, France; E-Mail: arm.colin@gmail.com

* **Correspondence:** Colin Armstrong; E-Mail: arm.colin@gmail.com

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Special Issue: The Importance of the Fascia for Manual Osteopathic Medicine

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Abstract

Progress in technologies, notably *in vivo* and *in situ* methods, has equipped scientists with the necessary skills to explore the living human body in increasingly minute detail. This has led to a better understanding of the dynamic interplay between the various elements that make up the living human body. To further understand the interplay, this research focuses on the insights and observations of the founders of osteopathy, who placed great importance on the role of fascia in the body. Modern anatomical investigation still relies heavily on dissection to describe the structural organization of living organisms. Therefore, at present, a major challenge faced by modern anatomists is to move towards a more holistic and integrative understanding of the unity, continuity, and dynamic interplay between the various elements that come together to create the living human form.

Keywords

Fascia; osteopathy; continuity; complexity; matrix biology; multifibrillar network; mechanobiology; fluid dynamics; structure-function relationships

1. Introduction

A new biological conception of life that emphasizes networks, patterns of organization, and complexity is slowly emerging, moving beyond a mechanistic, reductionist, and linear way of thinking. Anatomists are gradually beginning to think in terms of functional anatomy and integrated systems, as opposed to independent structures. Living systems appear to be composed of networks at all levels - networks within networks, which can be defined as - “a complex web of relationships between parts of a unified whole or an integrated whole whose properties cannot be reduced to its parts” [1]. Living systems are “open systems” that need a continual flux of matter and energy (they exist in a state of dynamic equilibrium), thereby making them relatively unstable [1]. Stillness, or static equilibrium, cannot exist in a living system [2]. A living organism is a system that constantly renews, regenerates, and reforms itself while maintaining its overall identity, form, and pattern of organization [1, 3].

Interestingly, living matter is governed by the universal laws of physics. Physicist Carlo Rovelli explains that space is not an inert box, “but rather something dynamic in which we are contained”, and that our world “seems to be less about objects than interactive relationships” [4]. Similarly, organisms sustain life utilizing “the complex, dynamic, three-dimensional interplay between millions of components, from the molecular to the multicellular” [5]. The living human form can be understood as “the infinite play of its combinations, through the reciprocal influencing and exchanging of correlations and information between its parts” [4].

AT Still, the founder of osteopathy, considered the body as an integral unit, a whole. He developed the principles of osteopathy based on the simple observation that the body is a dynamic functional unit. He was influenced by the writings of Herbert Spencer, who described the unity of all living systems in which “each part lives for and by the whole” [6]. Each part is connected-and relative-to all others within the histological continuum of living matter - from the surface of the skin to innermost parts of each cell, from the macroscopic level to the microscopic level, and across all scales, as suggested by recent research [7-10].

Osteopaths believe that the structure and function of the body work together and are dependent on each other. AT Still wrote that “fascial continuity, its nervous system investments, and vascular relationships clearly demonstrate how all parts work together. The human body is a unity of function” [11]. He also understood the reciprocal relationship between structure and function, as illustrated by this quote: “there is no real difference between structure and function; if structure does not tell us something about function, it means that we have not looked at it correctly; they are two sides of the same coin” [11].

The osteopathic medical profession was founded by a group of American doctors in the years following the Civil War. At that time, without antibiotics or vaccines, many medical treatments and unsanitary surgical practices were followed by the physicians, which were hazardous and often led to more sickness. The emergent osteopathic profession rejected reductionist, short-term interventions, which helped in treating only symptoms. Early osteopathic physicians focused on preventing diseases and maintaining health. They believed that the body has an inherent capacity to heal itself, and they called for this ability to be respected and harnessed. Thus, the focus was on “looking for health” rather than treating disease. This is the context in which AT Still set out the tenets of the osteopathic profession, and it is in this context that the writings of Still and other founders of osteopathy are recalled in this paper. They were pioneers in the development of an understanding of the importance of fascia. One of the aims of this paper is to explore how recent research lends support to the insights and observations of the founders of osteopathy.

As indicated by the latest technology, fascia plays an important role in maintaining the complex relationships between structure and function in the living body and also in fluid dynamics, matrix biology, and mechanobiology. Moreover, fascia acts as a unifying element within the living body, thereby facilitating movement, stability, and the integration of the various body systems. However, there is still some disagreement on precise fascial nomenclature and whether or not certain tissue types can be defined as fascia. Modern anatomy textbooks still rely heavily on dissection as a source of anatomical description and terminology; however, recent research suggests that this is not a true reflection of the architecture and function of the living body. Therefore, one of the major challenges facing modern anatomists is to break away from the restrictive confines imposed by adopting dissection as the main source of information about the anatomy of the living human body. Also, there is a need to move towards a more holistic, integrative understanding of the unity, continuity, and dynamic interplay between the various elements that come together to create the living human form. This is another theme that will be developed throughout this paper.

2. Discussion

The latest technological advancements enable researchers to explore the living human body in minute detail and at different scales of observation, i.e., *in vivo* and *in situ*. This provides valuable information about the "living body" as opposed to the "anatomical body." There is a significant difference between a dissected, disassembled cadaver, or "anatomical body", as presented in anatomy textbooks, and a living organism. As valuable as dissection may be, it does not provide an entirely accurate representation of the complex three-dimensional organization of living matter inside the living human body, especially at the microscopic level. Phischinger argued that the cell cannot be fully understood without taking its natural environment into account [12]. Research carried out *in vivo* by Guimberteau has provided visual evidence of the behavior of cells in their natural environment, notably the direct mechanical influence of the fibrous connective tissue of the extracellular matrix (ECM) on cells [7].

The cell and its requirements for optimal function - a supply of nutrients for cellular respiration and metabolism, and the removal of waste products - was central to Still's reasoning [13]. Nutrients and waste products are known to travel through the ground substance of the ECM. "Every function and every process in the living body, therefore, involves the ECM in some way" [12]. This introduces the notion of the "quality" of the ECM and the consideration of factors that either encourage or hinder the transport of these substances to and from the cell. The mechanical relationship between the cell and its microenvironment, the ECM, is, therefore, a good place to start when discussing the fundamental role of fascia in the living body.

2.1 The Extracellular Matrix

Histologist Albert Pischinger described the ECM as a "system of systems" because it is the one system that touches all other systems in the body [12]. Research by orthopedic surgeon Jean-Claude Guimberteau suggests that the ECM is highly organized, with its own three-dimensional architecture of collagen fibers and fibrils that support and connect the cells that are housed in it [7]. Dr. Guimberteau's films (based on the innovative use of endoscopic filming) reveal the intimate mechanical relationship between cells and the fibrillar network in which they are embedded [7]. Forces are seen to disperse in all directions across this continuous multifibrillar network and exert a direct influence on the cells via mechanotransduction.

The discovery of integrins, transmembrane proteins that span the cell membranes and connect the cytoskeleton to the ECM, and the subsequent discovery of mechanical links between the cytoskeleton and the cell nucleus [14, 15] revealed the presence of a continuous mechanical network that extends throughout the body, reaching the innermost parts of each cell.

Oschman calls this the "living matrix", which includes "all of the connective tissues and cytoskeletons of all of the cells, throughout the body" [9]. The living matrix "has no fundamental unit or central aspect, no part that is primary or most basic. The properties of the entire network depend upon the integrated activities of all the components. Effects on one part of the system can and do spread to others" [9]. This connective tissue continuum appears to serve as a body-wide, mechanosensitive signaling network [16] and is present at all levels, i.e., from molecules to cells, tissues, and the entire human form (from the cell to the organism as a whole) [17].

Mechanobiology is a field of research that studies the cell's responses to various mechanical cues or, in other words, provides information about the mechanosensitivity of cells. At the cellular level, mechanical forces of the surrounding ECM influence the cell's structure and function and thereby exert an influence on a wide range of physiological and pathological processes, such as inflammation, wound healing, and cancer [18, 19]. Therefore, it has been postulated that abnormal force patterns acting across the ECM could interfere with cellular function, and perhaps playing a role in various disease processes [20]. Transmission pathways of mechanical forces are multidirectional and complex, with an uneven distribution of forces running in every conceivable direction. Load distribution within the tissues is therefore not linear [21]. Based on these observations, Guimberteau considers the ECM, the natural microenvironment of the cells, to be as important as the cells [7].

The body appears to be structured by a continuous body-wide fibrillar system in which specialized cells carry out specific functions depending on where they are located. Guimberteau suggests that all the organs of the body are formed within this single, continuous fibrillar framework [7], whose architecture remains the same regardless of the type of tissue, its function, its location, and the cells it contains [7]. This is an entirely novel way of considering the anatomy of the human body. Guimberteau makes a broad distinction between the cells of the organism, regardless of their location, type and function, and their supportive framework [7]. Levin makes a similar distinction between the parenchymal cells and the connective tissue that connects and supports them throughout the body [22].

Oschman explains that the great systems of the body - the circulatory, nervous, musculoskeletal, and digestive systems - and the various organs and glands are bound together by a continuous connective tissue network or "fabric" [9].

2.2 What is Fascia?

The different types of fascia are now considered to be part of a "fascial system" [22]. The fascial system is increasingly recognized as "the unifying structural element of the body and a key to understanding the reciprocal interrelation between structure and function" [23]. Fascia is ubiquitous, and is found everywhere in the body. However, it is not clear what exactly is, and perhaps more importantly, what is not fascia?

The search for a comprehensive, widely accepted, and all-inclusive definition of fascia is ongoing. It is generally agreed that the fascial system forms "a three-dimensional continuum of predominantly collagenous loose and dense fibrous connective tissue that permeates the entire body" [24]. It is an organized but irregular supportive net, or web, that "reaches through all body elements" [25].

A classification system, proposed in 2012, categorized fascia into four different types based on gross anatomy, histology, and biomechanics - linking, fascicular, compression, and separating [26]. In 2014, the Fascia Nomenclature Committee (FNC) was established by the Fascia Research Society to address the confusion and inconsistent usage of the term "fascia." The committee considers this to be an ongoing process. In 2017, the FNC proposed two distinct terminology recommendations: "a fascia" and "a fascial system." The first is a morphological/anatomical definition, and the second is a functional definition [27]. The fascial system is described as a "three-dimensional continuum of soft, collagen-containing, loose and dense fibrous connective tissues that permeate the body" [28]. The FNC suggests that this system "surrounds, interweaves between, and interpenetrates all organs, muscles, bones and nerve fibers, endowing the body with a functional structure, and providing an environment that enables all body systems to operate in an integrated manner" [27, 28].

Fascia develops as a single tissue, the mesenchyme, during embryological development [28]. Scarr states that "bones, muscles, and fascia are comprised of and linked together by the same fibrous tissue." As they all have the same common origin in cells of the embryonic mesenchyme, they can no longer be considered as separate systems but "mutually dependent specializations of the same tissue" [29].

Tozzi refers to a "distinct fascial differentiation of a body-wide structural 'net' extending from the macroscopic to the cellular depth and sharing a common embryological origin. Therefore, despite local differences in structure and form, including fiber arrangement, direction, and density, the fascia shows a hierarchical continuity at different levels of complexity that truly makes it a system between and within the body systems" [17]. Van Der Waal describes "a tensional network in which all organs and structures are embedded", a fascial web in which "everything is both connected and separated" [30].

Van der Waal suggests two definitions of fascia, a "narrow" definition of a continuous network of fascial structures and a "broader" definition of fascia as "a matrix - connective tissue - fluid continuum" [30].

Guimberteau has demonstrated "a continuous, tensional, fibrillar network within the body, extending from the surface of the skin to the periosteum - a global network that is mobile, adaptable, fractal, and irregular" [7]. He proposes that this network of hydrated collagen fibers forms the basic structural architecture of the human body and a framework in which cells develop to form the various organs [7]. This raises several questions. Could this vast, all-pervasive fibrillar network revealed by Guimberteau provide the basis of a "broad" definition of fascia? Guimberteau has demonstrated that the fibrous collagen network extends into the ECM to provide an adaptable supportive network and scaffolding for cells. Levin considers the fibrous tissue that connects and supports the cells in the ECM to be part of the fascial system, as distinguished from the parenchyma - the functional tissue of an organism [7, 22]. Therefore, as

Guimberteau and Levin suggest, should this microscopic network of collagen fibers within the ECM be considered to be part of the fascial system? Does the fascial system terminate at the cell membrane, or does it extend beyond the cell membrane to the cytoskeleton and the intracellular matrix, as Guimberteau and Oschman suggest? Should bone be considered an integral part of the fascial network, as suggested by Guimberteau and Levin [7, 22]?

Blood and blood vessels are also formed in the embryo from mesenchyme. Blood could therefore be considered as a tissue, and not fluid, with the capillaries transporting "liquid tissue" to the interstitial areas [31]. Bordoni considers blood to be part of the fascial system and defines fascia as any tissue that is capable of responding to mechanical stimuli and describes the fascial continuum as "a perfect synergy between different tissues, liquids, and solids capable of supporting, dividing, penetrating, feeding and connecting all regions of the body" [31].

2.3 Guimberteau's Multifibrillar Network

Guimberteau [7,32-39] revealed a multifibrillar, multidirectional, irregularly organized network of collagen fibers that extends from the surface of the skin to the nucleus of each cell. This fibrillar network provides a mobile and adaptable framework for cells throughout the body. Therefore, it plays a fundamental constitutive and structuring role in the body [7]. As a dynamic and self-adjusting system, it plays an essential role in the movement. Nothing stops and starts within this network - it is continuous and all-pervasive. It forms an interconnected network throughout organs, bone, muscle, and nerve. It provides the scaffolding in which cells are embedded, and along which certain cells appear to migrate. There are no empty or redundant spaces in the living body [7]. The fibrillar network is permanently hydrated in normal healthy tissue, thereby representing- a continuum of fibers and fluids that permeates every other system [7, 39].

Guimberteau's research has revealed that specific anatomical structures, such as ligaments, aponeuroses, muscular septa, and tendons, and different categories of fascia, such as superficial or deep fascia, all share the same basic fibrillar architecture and are all part of the continuous body-wide multifibrillar network. Depending on the location and function, only the density of the weave and the diameter of the fibers differ. For example, the epimysium, perimysium, and endomysium can be considered as separate anatomical structures for practical purposes, but in reality, they form a continuous, coherent, and functional structure, in which the muscle cells are embedded. They are not separate histological entities and are an integral part of the body-wide multifibrillar network. The fibers of the epimysium, perimysium, and endomysium are arranged in a completely irregular manner, in contrast to the longitudinal and parallel, *pseudolinear* orientation of the muscle cells [7, 39].

This is true with all biological systems, as they do not display true linearity [40]. Guimberteau's research has demonstrated that the architecture of the multifibrillar network is chaotic, irregular, and non-linear [7]. Blyum [40] explains that it is fundamentally impossible for a living system "that is so profoundly complex at all its different levels and size-scales" to behave in a linear manner.

2.4 The Fibrous Matrix of Organs and Bones

The composition of a bone can be described in terms of the mineral phase and the organic phase; out of these two phases, the water-insoluble mineral phase can be dissolved by weak acids [41]. The remaining organic matrix retains the form of the bone and is pliable and can be cut with a knife and tied in knots [22, 30, 41]. Therefore, Levin considers bone to be ossified fascia [22, 30]. Handoll describes bone as a “stiffened membrane” [3], and Guimberteau considers bone to be an integral part of the multifibrillar network [7, 39].

Similar to muscle cells, osteoblasts and other parenchyma cells are also embedded in the interstices of a fascial framework. Bone gains its rigidity by the binding of hydroxyapatite to this fascial fabric [22, 30]. However, unlike the rigid, brittle dry bone specimens that are used to study anatomy, living bone is flexible, pliant, plastic, resilient, and elastic. Heavy trauma will cause a bone to distort. If there is no fracture, the bone will recoil to its elastic ability, and a degree of distortion will remain within the bone as “intraosseous compression”, detectable by palpation as a change in the quality of the bone. Unless treated, this compression remains in the bone tissue indefinitely, as suggested by Handoll [3].

It has been demonstrated that the reticular framework of organs is independent of the cells of the organs. Sabin [42] described a labile framework that adapts to and supports the cells of each organ. When cells of an organ are removed by a process called decellularization, it can be identified by this framework alone because the reticular framework faithfully outlines the patterns of the cells of the organ [42, 43]. Decellularization also reveals the substantial fascial scaffolding, which supports Guimberteau’s hypothesis of an all-pervasive network of fibers and fibrils that extends throughout the body at all scales, from macroscopic to microscopic. This continuous network extends into the ECM, connecting and supporting the cells at the microscopic level.

It has been suggested that the dissection of cadavers encourages “dissective thinking” [29]. There is a significant difference between the dissected, disassembled “anatomical” body as presented in anatomy textbooks, and a living, functioning organism. However, extensive knowledge of both is necessary. The creation of planes and flat surfaces by the dissector’s scalpel is not an entirely accurate representation of the three-dimensional spatial organization of living matter inside a living organism, especially in terms of micro-anatomy. Sheets of fascia can be created using a scalpel during dissection to represent separate “layers” like the pages of a book. However, endoscopic exploration reveals that they do not appear to be arranged like this inside the living body but rather form an integral part of a three-dimensional, fluid-filled, fibrillar matrix [7].

Researchers are increasingly focusing on new technology to obtain detailed and precise three-dimensional images of the inner workings of a living body. For example, recently developed techniques such as lattice light-sheet microscopy (LLSM) [5] have enabled researchers to visualize the complex, dynamic, and three-dimensional interplay between various components that make up a living body. *In vivo* cell biology and, by extension, extracellular matrix biology can now be studied using a combination of LLSM and adaptive optics (AO) [5]. The cell can be studied in its natural environment within a living body with this technology. It provides precise images of multicellular environments at high resolution in space and time, thereby providing a new perspective on the environmental factors that regulate physiology [5].

2.5 Movement of Fluids Through a Continuous Network of Interstitial Spaces

Real time histological images of human tissues can be obtained by a novel endoscopic-assisted technique called confocal laser endomicroscopy [44]. This technology has been used to demonstrate the continuity of fluid--filled interstitial spaces within the fibroconnective tissue of the body [44]. These spaces are described as "macroscopically visible spaces within tissues - dynamically compressible and distensible sinuses through which interstitial fluid flows around the body" [44]. Cenaj et al. describe a continuous network of fluid-filled interstitial spaces within the demonstrated fibrous network [43]. A significant finding is that these interstitial spaces are continuous across tissue and organ boundaries in humans and that they have been found in tissue sections throughout the body [43].

Osteopathic treatment is thought to have a positive action on local circulation and drainage, thereby improving and optimizing the supply of nutrients and oxygen and the removal of metabolic waste products and inflammatory mediators [45, 46]. The free and uninterrupted flow of blood to the capillaries is essential for the maintenance and repair of the body. The significance of this function can be understood by the words of Still "the rule of the artery is supreme" [45]. Still and Sutherland both highlighted the importance of local circulatory mechanisms, including the drainage of metabolic waste products via the venous and lymphatic systems. Still wrote that "we strike at the source of life and death when we go to the lymphatics" [47].

Lymphatic channels run through the fascia and are completely integrated into the multifibrillar network [7]. An uninterrupted movement of lymphatic fluid occurs when this network is well hydrated and mobile. This is one example of why optimal mobility, hydration, and adaptability of the multifibrillar, microvacuolar network is important in the function of normal healthy tissue [39].

2.6 Fluid Dynamics

As indicated by recent research, osteopaths have long suggested that connective tissue networks contain fluid and are part of a body-wide communication network [43]. AT Still wrote that "the soul of man, with all the streams of pure living water, seems to dwell in the fasciae of his body" [48]. He also wrote of the deleterious effects of the "delay and stagnation of fluids while in the fascia" [49]. Sutherland wrote that fluid is transported throughout the body within the fascia. He described a "tide" that travels throughout the body, creating a flow of interstitial fluid that bathes every cell [17]. He described a technique to influence this "tide" and to promote "an interchange that occurs between all the fluids of the body - and I mean *all* the fluids" ("all through the viscera, the connective tissue, and the fascia") [50]. Wales [51] described "an intensified interchange between all of the fluids of the body." She went on to state that "it is evident that the reaction is systemic and includes the whole body, even within the bones" [51]. Therefore, long before the discovery of interstitial spaces that are continuous across tissue and organ boundaries in humans, early osteopaths understood their significance in the movement of fluid [45].

A significant observation is that the above-mentioned interstitial spaces are not empty - they are filled with stainable hyaluronic acid and proteoglycans. Benias et al. hypothesize that normal functional activities of different organs as well as "disordered fluid dynamics" could play a role "in the setting of disease, including fibrosis and metastasis" [44].

As long ago as 1994, Shultz and Feitis proposed that the fascial web "acts like a riverbed containing the flow of interstitial fluid" [25]. Myers reminds us that fascia is an aqueous medium and calls for the inclusion of Guimberteau's multimicrovacuolar system in the biotensegrity model (which depicts the skeletal system as a non-random arrangement of compression elements knitted into the tensional fabric of fascia). He also underlines the importance of the flow (and, in some circumstances, the lack of flow) of fluid through the interstitium as a factor that must be accounted for in the biotensegrity model [52].

Therefore, the mobility and adaptability of the permanently hydrated body-wide multifibrillar, microvacuolar network, as described by Guimberteau appears to play an essential role in the function of normal healthy tissue [39].

2.7 Densification and Stiffness of Tissue

Mechanotransduction is a bidirectional means of communication between the ECM and the cell, which is mediated by the cell microenvironment [14, 15, 39]. Bissell describes this as "dynamic reciprocity" between the ECM on the one hand, and the cytoskeleton and the nuclear matrix on the other hand [14]. The cell responds with an electrochemical cascade [31], and as demonstrated in Guimberteau's films, the mechanical deformation of cells occurs as an adaptive response to mechanical stimuli [7]. Research carried out by Bissell has demonstrated that all the cells of an organ must be "integrated into an architectural and signaling framework such that each cell knows exactly, which commands to execute at any given time." Any failure can result in "a spectrum of dysfunctions, including cancer" [53].

The "quality" of the ECM - its intrinsic stiffness or flexibility and its ability to transmit mechanical forces optimally - is to a large extent determined by the content and adaptability of the matrix [18, 19]. Abnormal stiffness of collagen fibers in the ECM appears to have deleterious effects on local tissue health [39].

Much interest has recently focused on the hyaluronan content in the fascia, notably in areas of densification compared to adjacent areas of fascia [54]. Osteopaths have long maintained that localized areas of somatic dysfunction and "fascial drag" will impede local circulation, the flow of interstitial fluids, and drainage of the interstitial areas by the venous and lymphatic systems [55]. Research by Swartz [56] suggests that pre-lymphatic fluid contains information about the state of the ECM from which it drains. Encouraging and facilitating the movement of this information-rich fluid from the interstitium into the lymphatic system may benefit the tissues and provide wider health benefits.

Manual therapy is thought to help move cellular waste into the lymphatic system until it is filtered and eliminated. Recent research utilizing novel MRI technology has confirmed this, wherein manual therapy techniques exhibited a favorable impact on the proportion of "bound" vs. "unbound" water in the interstitial ground substance. A healthy ground substance is thought to contain a high proportion of "bound water" (water molecules that associate closely with glycosaminoglycans). An increase in metabolic waste products or local inflammatory products is thought to contribute to an increase in the proportion of "unbound water" (stagnant bulk water) in the ground substance. It is postulated that the manual techniques used in this study shuttle stagnant bulk water into the venous and lymphatic drainage systems. This allows fresh water from blood plasma to enter the area and associate more closely with the glycosaminoglycan elements, increasing the proportion of "bound water" in the ground substance [57].

It has been demonstrated that the endothelial cells of the terminal or "initial lymphatic capillaries" are directly connected to the collagen fibers of the ECM via "anchor filaments." Interstitial fluid appears to enter the initial lymphatics via "inlet valves" [58]. These valves could be affected by pockets of local stiffness in the surrounding microenvironment, with subsequent loss of adaptability of the collagen fibers in the ECM; thus, this process could interfere with the drainage of interstitial fluid into the lymphatic system.

Oncology researchers are showing renewed interest in the microenvironment surrounding tumors [14, 15], especially because of the hypothesis that stiffer environments may contribute towards metastatic growth [19]. Research has suggested that “stiff aligned collagen fibers” in the ECM may “pave the way for tumor cells” [59]; however, very little is known about the factors responsible for the stiffening of these collagen fibers. Inflammation and fibrosis are well-recognized contributors to cancer, and physical-based therapies have been shown to reduce connective tissue inflammation and fibrosis [19]. The same researchers suggest that “physical-based therapies may have direct beneficial effects on cancer spreading and metastasis.” However, the question remains as to what causes ECM stiffness and whether this stiffness can facilitate the spread of tumors in the absence of other factors.

This is of particular interest in the light of Guimberteau’s observations of collagen fibers aligning themselves in the direction of an applied force and then returning to their previous spatial configuration once the force is removed [7]. Collagen fibers in healthy living tissue are arranged in an irregular, chaotic manner, and the alignment of fibers in one direction is never permanent.

During dissection of human cadavers, Upledger and Vreedegevoord observed that under “normal” circumstances, the “elasto-collagenous fibers of the dural membrane are interlaced and appear disorganized” [52]. During some dissections, they also observed abnormal and permanent alignment of collagen fibers in the dura mater. They advanced the hypothesis that this is a response to abnormal and prolonged constraints acting on the tissues involved. They suggested that when the dural membrane is subjected to abnormal tension in a specific direction over a considerable period, the fibers within the membrane appear to react by organizing and aligning themselves in the direction of tension and are unable to return to their initial configuration [52].

Guimberteau’s films of normal healthy tissue show how fibers in the network arrange themselves in the direction of the tension of an applied force, and then return towards their initial configuration when the force is removed [32-38]. However, any changes in the mobility and adaptability of the fibers within the network would appear to affect the healthy function of the tissue in question [7].

In situ imaging techniques, such as shear wave elastography, have shown that malignant tumors are stiffer than benign tumors [60]. Transrectal shear wave elastography is used as a non-invasive method to detect and characterize prostate cancer. Because of the stiffness of cancerous tissue, the shear waves are slowed as they pass through a tumor. The technique allows operators to differentiate between cancerous and benign tissue in the prostate [61, 62]. It accurately detects cancer foci and reveals significant differences in stiffness between cancerous and benign tissue.

2.8 Alternative Channels of Communication

There is a growing body of research to support the hypothesis that fascia may be the tissue through which alternative systems of fluid and electrical energy flow.

Guimberteau’s films reveal the omnipresence of fluids in the interstitial areas [7]. Benias et al. [44] have demonstrated the existence of a body-wide network of fluid-filled interstitial spaces [43, 44]. “Although this lacks detailed microscopic confirmation”, osteopaths have suggested the existence of a body-wide communications network of fluid-containing interstitial spaces in connective tissue [43].

The tensegrity model considers the whole body as a three-dimensional viscoelastic matrix, "balanced by an integrated system of compression tension forces in dynamic equilibrium" [63]. "An applied force can influence any part of this system, from cellular to whole-body and vice-versa via a non-linear distribution of forces" [63]. Local stimuli can therefore lead to global reorganization [64]. This is because of the structural and tensional continuity within the living body, which provides "an electromechanical semiconducting matrix that can generate coherent vibratory signals throughout the body", in other words, a communication continuum [63, 65]. Oschman considers the connective tissue fabric as a body-wide semiconducting communication network that is capable of carrying bioelectric signals "between every part of the body and every other part" [9].

Far from being simply a support structure or passive container, the fascial network now appears to play a central role in various body-wide communication networks. In the 20th century, a huge amount of research, mainly *in vitro*, was carried out on the cell. The focus is now shifting towards research into the ECM and the fascial system and the mechanisms by which cells interact with the ECM. This is a two-way dialogue that can be adversely affected by mechanical issues and disturbed structure-function relationships within living tissues [39, 58], thereby making it important for the health and survival of the organism [15, 16].

2.9 Scar Tissue and Adhesions

Endoscopic observations provided by Dr. Guimberteau's research show that scars are areas of disturbed mobility within the multifibrillar network. A scar is an area of real structural chaos, with no functional purpose, as opposed to the normal fibrillar organization that can also be described as a chaotic system; however, this- chaos is more in the mathematical sense and has an underlying order. The formation of scar tissue introduces "real" disorder into the fibrillar system, and adhesions (bands of scar tissue that join two internal body surfaces that are not usually connected) are responsible for the disappearance of normal dynamic fibrillar harmony and adaptability.

All surgical procedures are necessarily destructive because the surgeon must gain access to the operation site, destroying connective tissue and disturbing the internal architecture of the body. It has been observed that the fascia that has been destroyed by surgery is replaced by scar tissue. As we have seen, fascia plays a significant and vital role in movement by facilitating the integration and coordination of the movement of adjacent anatomical structures and has a knock-on effect on systems, such as the circulatory, lymphatic, and nervous systems. This can be adversely affected by scar tissue. Guimberteau, therefore, calls for surgeons to destroy as little as possible of this precious tissue during surgery.

Scars are often overlooked by manual therapists or considered to be of minor importance, whereas osteopaths traditionally pay a lot of attention to them [66]. Scars appear to play a role in the symptomatology of many patients, and they are clinically observed to be the source of symptoms that are resistant to treatment. Therefore, they often require special attention. Lewitt [67], Upledger, and Vredegevoord [68] have written about the importance of treating scars resulting from surgery or injury. A scar often affects deeper anatomical structures and may therefore be the source of soft tissue dysfunction in areas far removed from the site of the scar. Adhesions and fixations in the peritoneum and the gliding areas between the viscera can exert a negative influence on visceral mobility and motility [69, 70].

The formation of scar tissue is an ongoing process - "neither static nor irreversible, but a continuous remodeling process" - and will therefore respond to manual interventions [30]. Apart from facilitating the repair of specific structures that have been damaged, manual therapy aims to ensure that functional harmony and equilibrium are restored to those parts of the body affected by trauma and that their functional relationships with the rest of the body are not compromised. Skillfully applied manual therapy to a healing wound can prevent chaotic and disorganized scar tissue [30]. The goal of manual therapy should therefore be to restore both local and global functional relationships and to ensure optimal integration of the scar tissue within the multifibrillar network [7, 36].

3. Conclusions

It is becoming increasingly apparent that the living body functions as an integrated unit, with fascia as the unifying element. The fascial system extends into every part of the body as a multidirectional web of fibers in which everything is at once connected and separated, enabling the various systems of the body to work together as a coherent, interdependent structural and functional entity. The conventional understanding of the human body as an assemblage of separate, distinct anatomical structures is being challenged by modern research that is providing a growing body of evidence of more porous and less permeable systems that extend across tissue and organ boundaries.

The role of fascia as a unifying system in the living human body is therefore now well established. Its relationships with all the great systems in the body have been demonstrated. Guimberteau's research has revealed the existence of an all-pervasive body-wide tensional network of collagen fibers at all levels of observation, from macroscopic to microscopic, from the skin to the periosteum. This permanently hydrated multifibrillar microvacuolar network is present everywhere in the body and has been demonstrated to play an essential role in movement. It extends into the ECM, where it provides a framework, or scaffolding, for cells and contains a continuous body-wide fluid-filled network of interstitial spaces. The implications of these discoveries are profound and wide-ranging. They indicate a need for a reappraisal of our understanding of the architecture and spatial organization of the living human form.

AT Still considered the human body as a fully integrated biological unit and understood the importance of fascia - a tissue that was considered until recently as an inert packing tissue. He recognized the all-pervasive nature of fascia at all levels of organization in the human body, the central role it plays in facilitating movement and coordinating the various systems in the body, and its importance in maintaining health. He also gained valuable insights into the complex structure-function relationships within the living body. These insights are being borne out by recent research made possible by technological advances that allow scientists to explore the living body in increasingly minute and precise detail.

Author Contributions

The author did all the research work of this study.

Competing Interests

The author has declared that no competing interests exist.

References

1. Capra F, Luisi PL. The systems view of life: A unifying vision. Cambridge, UK: Cambridge University Press; 2014.
2. Lowell S, de Solorzano SL. Everything moves: How biotensegrity informs human movement. Edinburgh, UK: Handspring Publishing; 2020.
3. Handoll N. Anatomy of potency: Energy osteopathy and quantum physics. Hereford, UK: Osteopathic Supplies; 2016.
4. Rovelli C. Seven brief lessons in physics. London, UK: Penguin Books; 2014.
5. Liu TL, Upadhyayula S, Milkie DE, Singh V, Wang K, Swinburne IA, et al. Observing the cell in its native state: Imaging subcellular dynamics in multicellular organisms. Science. 2018; 360: eaaq1392.
6. Tricot P. Ce qui marche, ce qui ne marche pas en ostéopathie. Paris, France: Josette Lyon; 2004.
7. Guimberteau JC, Armstrong C. Architecture of human living fascia: Cells and extracellular matrix as revealed by endoscopy. Edinburgh, UK: Handsping Publishing; 2015.
8. Oschman JL. The development of the living matrix concept and its significance for health and healing [Internet]. 2009. Available from: http://bti.edu/pdfs/Oschman_Living-Matrix-Concept.pdf.
9. Oschman JL. Energy medicine: The scientific basis. Edinburgh, UK: Churchill Livingstone; 2015.
10. Oschman JL. Structure and properties of ground substances. Am Zool. 1984; 24: 199-215.
11. Still AT. Philosophy of osteopathy. Indianapolis, Indiana, US: American Academy of Osteopathy; 1899.
12. Pischinger A. The extracellular matrix and ground regulation: Basis for a holistic biological medicine. Berkeley, California, US: North Atlantic Books; 2007.
13. Bel F. Plaidoyer pour une ostéopathie vivante: Plaidoyer. Vannes, France: Sully; 2020.
14. Bissell MJ, Hall HG, Parry G. How does the extracellular matrix direct gene expression? J Theor Biol. 1982; 99: 31-68.
15. The strings that bind us: Cytofilaments connect cell nucleus to extracellular microenvironment [Internet]. Lawrence Berkeley National Laboratory; 2017. Available from: http://www.sciencedaily.com/releases/2017/01/170126082521.htm.
16. Langevin HM. Connective tissue: A body-wide signaling network? Med Hypotheses. 2006; 66: 1074-1077.
17. Liem T, Tozzi P, Chila A. Fascia in the osteopathic field. Edinburgh, UK: Handspring Publishing; 2017.
18. Langevin HM, Nedergaard M, Howe AK. Cellular control of connective tissue matrix tension. J Cell Biochem. 2013; 114: 1714-1719.
19. Langevin HM, Keely P, Mao J, Hodge LM, Schleip R, Deng G, et al. Connecting (t)issues: How research in fascia biology can impact integrative oncology. Cancer Res. 2016; 76: 6159-6162.
20. Ingber DE, Wang N, Stamenović D. Tensegrity, cellular biophysics, and the mechanics of living systems. Rep Prog Phys. 2014; 77: 046603.

21. King HH, Janig W, Patterson MJ. The science and clinical application of manual therapy. Edinburgh, UK: Churcill Livingstone; 2011.
22. Levin SM. Bone is fascia [Internet]. 2018. Available from: https://www.researchgate.net/publication/327142198_Bone_is_fascia.
23. Tozzi P. A unifying neuro-fasciagenic model of somatic dysfunction – underlying mechanisms and treatment – part II. J Bodyw Mov Ther. 2015; 19: 526-543.
24. Zügel M, Maganaris CN, Wilke J, Jurkat-Rott K, Klingler W, Wearing SC, et al. Fascial tissue research in sports medicine: From molecules to tissue adaptation, injury and diagnostics: Consensus statement. Br J Sports Med. 2018; 52: 1497.
25. Schultz RL, Feitis R. The endless web: Fascial anatomy and physical reality. Berkeley, CA, US: North Atlantic Books; 1996.
26. Kumka M, Bonar J. Fascia: A morphological description and classification system based on a literature review. J Can Chiropr Assoc. 2012; 56: 179-191.
27. Adstrum S, Hedley G, Schleip R, Stecco C, Yucesoy CA. Defining the fascial system. J Bodyw Mov Ther. 2017; 21: 173-177.
28. Schleip R, Hedley G, Yucesoy CA. Fascial nomenclature: Update on related consensus process. Clin Anat. 2019; 32: 929-933.
29. Scarr GM. Biotensegrity: The structural basis of life. Edinburgh, UK: Handspring Publishing; 2018.
30. Lesondak D, Akey A. Fascia, function, and medical applications. Boca Raton: CRC Press; 2020.
31. Bordoni B, Marelli F, Morabito B, Castagna R. A new concept of biotensegrity incorporating liquid tissues: Blood and lymph. J Evid Based Integr Med. 2018; 23: 2515690X18792838.
32. Guimberteau J-C. Strolling under the skin. Pessac: Endo Vivo Productions; 2005
33. Guimberteau J-C. The skin excursion. Pessac: Endo Vivo Productions; 2009.
34. Guimberteau J-C. Muscle attitudes. Pessac: Endo Vivo Productions; 2010.
35. Guimberteau J-C. Interior architectures. Pessac: Endo Vivo Productions; 2012.
36. Guimberteau J-C. Skin, scars and stiffness. Pessac: Endo Vivo Productions; 2012.
37. Guimberteau J-C. Of cells, fibers and the living human body. Pessac: Endo Vivo Productions; 2017.
38. Guimberteau J-C. Homofasciaticus. Pessac: Endo Vivo Productions; 2018.
39. Armstrong C. The architecture and spatial organization of the living human body as revealed by intratissular endoscopy – an osteopathic perspective. J Bodyw Mov Ther. 2020; 24: 138-146.
40. Trewartha JE, Wheeler SL. Scars, adhesions and the biotensegral body. Edinburgh, UK: Handspring Publishing; 2020.
41. Lockhart RD. Anatomy of the human body. 2nd ed. UK: Faber & Faber; 1981.
42. Rena SF. Biographical memoir of Franklin Paine Mall, 1862-1917. Massachusetts, US: National Academy of Sciences; 1934.
43. Cenaj O, Allison DH, Imam R, Zeck B, Drohan LM, Chiriboga L, et al. Interstitial spaces are continuous across tissue and organ boundaries in humans. bioRxiv. 2020. DOI: 10.1101/2020.08.07.239806.
44. Benias PC, Wells RG, Sackey-Aboagye B, Klavan H, Reidy J, Buonocore D, et al. Structure and distribution of an unrecognized interstitium in human tissues. Sci Rep. 2018; 8: 1-8.
45. Lever R. At the still point of the turning world. Edinburgh, UK: Handspring Publishing; 2013.
46. Lever R. Finding the health. Edinburgh, UK: Handspring Publishing; 2016.

47. Still AT. The philosophy and mechanical principles of osteopathy. Indianapolis, Indiana, US: American Academy of Osteopathy; 1986.
48. Lee RP. The living matrix: A model for the primary respiratory mechanism. Explore. 2008; 4: 374-378.
49. Still AT. Philosophy of osteopathy. Indianapolis, Indiana, US: American Academy of Osteopathy; 1899.
50. Sutherland WG. Contributions of thought. Portland, USA: Rudra Press; 1998.
51. Walker T. Bones to fluids: A path to understanding wholeness [Internet]. IASI Yearbook of Structural Integration; 2014. Available from: https://listeninghandsseminars.com/wp-content/uploads/Bones-to-Fluids-A-Path-to-Understanding-Wholeness-Walker.pdf.
52. Myers TW. Tension-dependent structures in a stretch-activated system. J Bodyw Mov Ther. 2020; 24: 131-133
53. Bissell MJ, Labarge MA. Context, tissue plasticity, and cancer: Are tumor stem cells also regulated by the microenvironment? Cancer cell. 2005; 7: 17-23.
54. Hughes EJ, McDermott K, Funk MF. Evaluation of hyaluronan content in areas of densification compared to adjacent areas of fascia. J Bodyw Mov Ther. 2019; 23: 324-328.
55. Sutherland WG. Teachings in the science of osteopathy. Oakleigh, Victoria, Australia: Sutherland Cranial Teaching Foundation; 1990
56. Swartz MA. Immunomodulatory roles of lymphatic vessels in cancer progression. Cancer Immunol Res. 2014; 2: 701-707.
57. Menon RG, Oswald SF, Raghavan P, Regatte RR, Stecco A. T1ρ-mapping for musculoskeletal pain diagnosis: Case series of variation of water bound glycosaminoglycans quantification before and after fascial manipulation® in subjects with elbow pain. Int J Environ Res Public Health. 2020; 17: 708.
58. Cheng MH, Chang DW, Patel Km. Principles and practice of lymphedema surgery. London, UK: Elsevier; 2015.
59. Seewaldt V. ECM stiffness paves the way for tumor cells. Nat Med. 2014; 20: 332-333.
60. Zanetti-Dällenbach R, Plodinec M, Oertle P, Redling K, Obermann EC, Lim RY, et al. Length scale matters: Real-time elastography versus nanomechanical profiling by atomic force microscopy for the diagnosis of breast lesions. BioMed Res Int. 2018; 2018: 3840597.
61. Ahmad S, Cao R, Varghese T, Bidaut L, Nabi G. Transrectal quantitative shear wave elastography in the detection and characterisation of prostate cancer. Surg Endosc. 2013; 27: 3280-3287.
62. Wei C, Li CH, Szewczyk-Bieda M, Upreti D, Lang S, Huang ZH, et al. Performance characteristics of transrectal shear wave elastography imaging in the evaluation of clinically localized prostate cancer: A prospective study. J Urol. 2018; 200: 549-558
63. Tozzi P. Does fascia hold memories? J Bodyw Mov Ther. 2014; 18: 259-265.
64. Chen CS, Ingber DE. Tensegrity and mechanoregulation: From skeleton to cytoskeleton. Osteoarthr Cartil. 1999; 7: 81-94.
65. Pienta KJ, Coffey DS. Cellular harmonic information transfer through a tissue tensegrity-matrix system. Med Hypotheses. 1991; 34: 88-95.
66. Chaitow L. Palpation skills. London, UK: Churchill Livingstone; 2000.
67. Lewit K. Manipulation therapy in rehabilitation of the locomotor system. London, UK: Butterworths-Heinemann; 1987.

68. Upledger J, Vredevoogd J. Craniosacral Therapy. Seatle, USA: Eastland Press Inc; 1985.
69. Wasserman JB, Copeland M, Upp M, Abraham K. Effect of soft tissue mobilization techniques on adhesion-related pain and function in the abdomen: A systematic review. J Bodyw Mov Ther. 2019; 23: 262-269.
70. Barral JP. Visceral Manipulation. Seattle, USA: Eastland Press; 2006