

## BioTensegrity

### Fascia and the fallacy of biomechanics. Part 1

John Sharkey, Clinical Anatomist.

MSc., Department of Clinical Sciences, University of Chester/NTC, Dublin , Ireland

\*Correspondence to:

John Sharkey MSc.

University of Chester/National Training Centre

16a St Joseph's Parade

Dorset St

Dublin 7, Ireland

E-mail address: [john.sharkey@ntc.ie](mailto:john.sharkey@ntc.ie)

[www.johnsharkeyevents.com](http://www.johnsharkeyevents.com)

#### Introduction

Biotensegrity is emerging as the most significant development in human anatomy in recent years.

With important ramifications for a wide range of medical practitioners including surgeons, bio-engineers and human movement specialists. Bespoke dissection techniques are providing a new vision and understanding of the continuity of the human form. A fresh look at the human fasciae highlights its role in providing continuous tension throughout its network. The term "Tensegrity" was coined by Buckminster Fuller combining the words 'tension' and 'integrity'. Fuller's student Kenneth Snelson built the first floating compression structure of "tensegrity" in 1949 while Dr Stephen Levin an orthopedic surgeon was the protagonist of "BioTensegrity" in the early 1970's. As a Clinical Anatomist I have investigated this model and the role of fascia in my dissections to better understand the mechanisms of human movement and chronic pain while providing new anatomical knowledge and awareness leading to less invasive surgical and non-surgical therapeutic interventions.

#### Understanding BioTensegrity

Borrowing from Fuller's term "tensegrity", a syntactic of "tension" and "compression", Levin (1975) added the term "Bio" referring to living structures. BioTensegrity is the application of Fuller's tensegrity concepts to biologic structure and physiology. In the BioTensegrity model the limbs are not a collection of rigid body segments. The upper and lower limbs are semi-rigid, non-linear, viscoelastic bony segments. These segments are interconnected by non-linear, viscoelastic connectors including cartilage, joint capsules and ligaments, with an integrated non-linear, viscoelastic active motor system, the muscles, tendons and fascia (connective tissue). BioTensegrity counters the notion that the skeleton provides a frame for the soft tissues to hang upon. Instead BioTensegrity structures are integrated pretensioned (self-tensioned) continuous myofascial networks with floating discontinuous compression struts (skeleton) contained within them. A column whose center of gravity is constantly changing while its base is rapidly moving horizontally would require forces too great to consider. The forces become incalculable if the column is composed of several rigid bodies, hinged together by flexible, virtually frictionless joints.

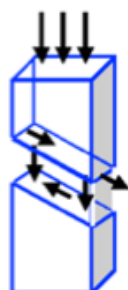


Figure 1. When simple compressive loads are applied, compressive and shear stress must exist on planes that are oriented obliquely to the line of application of the load (Levin 1995. With permission).

A rigid column needs to be base heavy to support the incumbent load above. Internal shear forces are created by the weight of the structure (Fig. 1), which in turn would be destabilizing. Energy would be required in large amounts to keep the structure intact. Humans are Omni directional, as are all biological organisms, in order that the tension elements

function at all times in tension regardless of the direction of applied force, while the compression elements in biological structures "float" in a tension network (Levin 1995).

#### Building a living structure

To construct a biologic organism on the principles of tensegrity, the tensegrity truss must be linked in a hierarchical construction. Starting at the infinitely small sub cellular component. Importantly it must have the potential to build itself. The structure would be one integrated tensegrity truss that evolved from infinitely smaller trusses that could be both structurally independent and interdependent at the same time. Ingber (2000) described this truss as the icosahedron (Fig. 2)

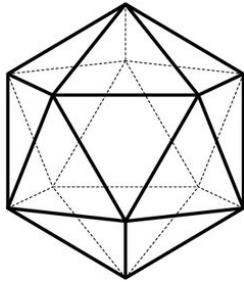


Figure 2. Icosahedron

Ingber found conclusive evidence that tensegrity provides the best explanation for the cytoskeleton of the cell. In fact Ingber also states that it is not possible to explain why skin stretches when muscle contracts other than by tensegrity.

#### No bones about it

Bone brittleness is approximately the same in Marsupials as in a Rhinoceros as the stiffness and strength of bones is roughly the same in all animals. Animals bigger than a lion, such as horses, running or jumping on their slim limbs, would break and fracture their bones with a leap. Based on linear mechanical laws, which are the foundation of biomechanical models, animal mass must cube as their surface area is squared. This should mean that animals as big as a Rhinoceros will collapse under their own weight. Working elastically at strains around a thousand times higher than strains that ordinary technological solids can withstand demonstrates that biological tissues behave differently than non-biologic materials. If this was not the case Levin (1982) informs us that the skull should explode with each heart beat due to the blood vessels expanding and crowding out the brain. As they reach fullness the urinary bladder should thin and burst. The pregnant uterus should burst with the contractions of delivery. Not exclusively, mechanical but also physiologic processes would be inconsistent with linear physics. Pressure within a balloon decreases as a balloon empties. The heart of the problem is that there are several assumptions regarding biologic tissues that are not valid. Biologic tissues, including muscles and fascia, have nonlinear stress/strain curves. Unfortunately, in biomechanics the initial premise that muscles, fascia, and indeed, any biologic material, can be bound by the rules of hard matter physics is, according to the information coming out of the condensed soft matter laboratories, flawed. Ligaments and fascia, bones and cartilage would do little to support our upright forms if not for the collective activity of an integrated myofascial system.

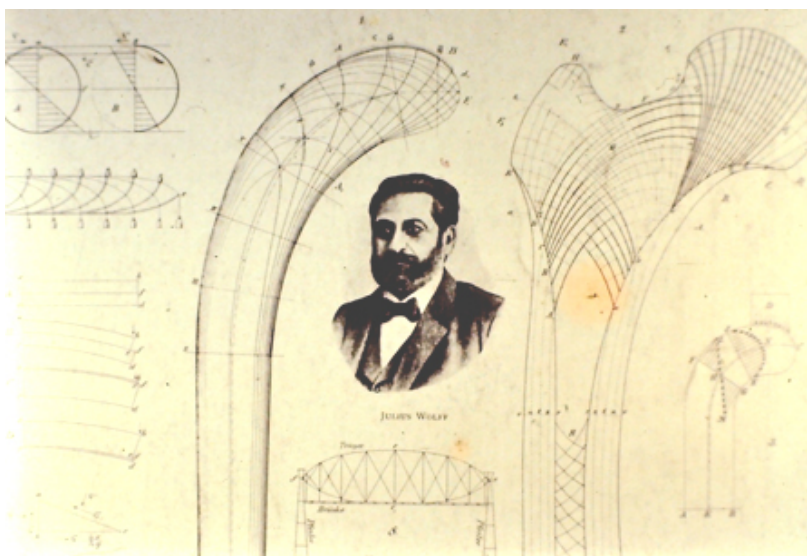


Figure 3. The denser bone is laid down where the compression stress is greatest. Conversely, the softest bone is where there is the least compressive load. Therefore, by examining bone density it is possible to determine what bone takes the most stress, and which the least. For example, the calcaneus and the metaphyseal ends of long bones take little compressive loads (Wolff's Law in bone).

### The cellular level

At the cellular level, using fluoroscopic imaging, Guimberteau et al (2010) provided strong visual evidence that fascia contains a water filled vacuolar system that is capable of sliding independent of the rate of contraction of muscle. In turn it is capable of facilitating and supporting capillaries throughout the fascia. Sharkey (2012) provided fresh frozen cadaver images (Fig 4) of the fascia profundus at the macro level reflecting this fractal microvacuolar structure while revealing an icosahedron like (tensegrity) composition where fractal elements inter-relate, creating a body wide framework or network. This structure is able to change or maintain shape and form within a fluid base allowing deformation followed by a return to its original state, whilst maintaining volume. This creates a stable, yet flexible environment necessary for fascia to act as a medium for force transmission (Huijing, 2009).

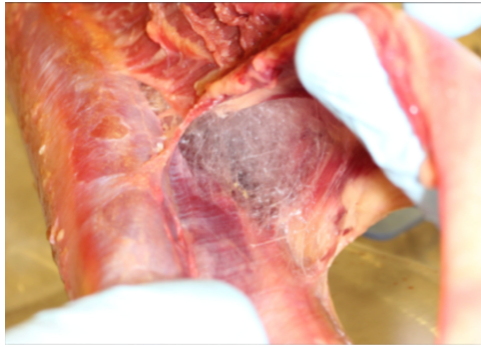


Figure 4. Providing a stretching force to the tissues of the anterior forearm, on a fresh frozen cadaveric specimen, Sharkey, J., highlights the fractal, chaotic arrangement of the deep fascia. (Photo by Sharkey, J. 2010)

This new model for biologic structures based on the concept of tensegrity identifies fascia as the tensional, continuous member. In a tensegrity continuous tensile forces (from the myofascia tissue) provide an “ocean” within which the struts float (in the human body these could be the bones which are not continuous with each other and they do not transmit compression directly onto each other). The tensional members are continuous and distribute their tension load directly to all other tensional members as described by Fuller in 1961. The fascial oceans become seas, lakes, rivers, streams and brooks (Sharkey. 2008). Newtonian, Hookian and linear mechanical properties are the basis for the building of all things non-biological (Levin 1995). This description supports the more recently accepted image of a continuous tissue, ubiquitous in nature, connecting left to right, front to back, top to bottom, embracing and permeating the entire body. Mesenchymal derived connective tissues providing a body wide network of communication (Schleip and Muller. 2013).

The visceral organs integrate structurally and physiologically into this system. There are no limb segment boundaries and the smaller bones and joints of the hands and feet fully integrate into the BioTensegrity model. The spine is a tensegrity turret that integrates with the limbs, head and tail and also to the visceral system. A change of tension anywhere within the system, such as the mid back, is instantly signaled to everywhere else in the body such as the sphenobasilar synchondrosis chemically and mechanically. There is a total body response by mechanical transduction. The structure works equally well right side up, upside down, in the sea, land, in the air or in space. It resolves many of the inadequacies of present biomechanical models.

Van der Wal (2009) suggests this dynamic connection between the connective tissue and the muscle is a “structural support” capable of adapting to increasing or decreasing joint range and also distance between bones throughout the joint range of motion. Van der Wal (2009) refers to these dynamic connections as “Dynaments”. These dynaments are not necessarily situated directly next to the joint cavity or in the deep part of the joint region. Van der Waal contends that some muscles have these specialised connective tissue structures at the proximal end only, some at the distal end only, some at both ends, and some at neither end. Fascia plays an important role in supporting muscle contraction as it links muscles together and non-muscular structures by means of these myofascial pathways and by direct attachment of muscles into the connective tissue structures around the joint (Sharkey, J. 2012. Fig. 5). Van der Wal, (2009) has informed us that none of the muscle fibers of supinator insert directly onto the humeral epicondyle, but attach by means of a connective tissue apparatus. Nerve endings in these structures are in greater number where the stresses are the highest, particularly in the proximal or distal end of the ‘dynament’.



Figure 5. Fascial collagen links between Palmaris Longus and associated neighbouring muscles. (Photo Sharkey, J., 2012)

Several research studies have revealed fascial connections resulting in myofascial force transmission between both adjacent and antagonistic muscles (Bojsen-Moller et al. 2010). A vital mechanism for interaction between muscles is extramuscular myofascial force transmission, which is essentially the generator for intermuscular myofascial force transmission. Myofascial interaction was shown for synergistic muscles involving both intermuscular and extramuscular transmission (Huijing and Baan 2001; Huijing, 2003).

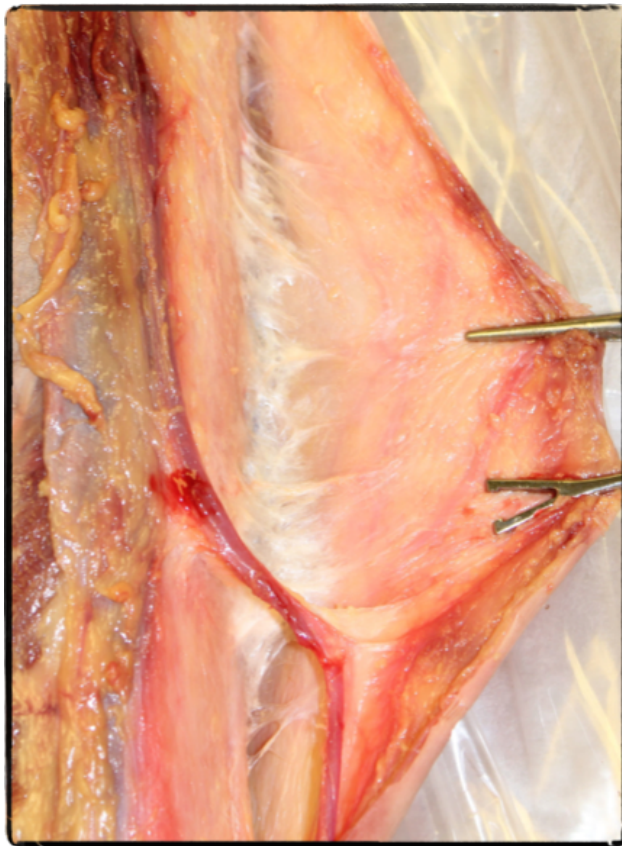


Figure 6. Strong septa from the deep fascia are exposed as the skin and subcutis is distracted. (Sharkey, J. 2013)

Dictated by changes in movement and posture mechanical forces, comprising of tension and compression (the members of BioTensegrity) may provide a means of communication resulting in connective tissue signaling (Fig. 6). Similar to Langevin (2005), Purslow and Delage (2012) propose that the fascia translates these signals into a whole body communication system. Such connective tissue signaling would be affected by changes in posture and motion and may lose mobility in pathological conditions or when experiencing pain. Due to the intrinsic relationship that connective tissue has with, among others, the lungs, intestines, heart, spinal cord and brain, connective tissue signaling may have a reciprocal influence on the functions, normal or pathological, of a wide spectrum of organ systems.

Reeds discovery (in Findley 2012) that hyaluronans, which are osmotically active compounds, are an essential ingredient in the interstitial matrix, and when given free access to fluid will swell, is potentially an important finding and one which requires more attention and investigation. This swelling is restrained by extracellular matrix fibers through  $\beta$  1 integrin mediated contraction when they are actively tensed by connective tissue cells. This demonstrates the role that tension plays in restraining the extracellular ground substance, which normally would be under-hydrated, from retaining fluid thereby reducing its capacity to swell.

## Fascia- A Question of Proprioception

Sensory neural fibers have been identified within fascia utilizing unique staining techniques coupled with electron microscopy. Stecco et al (2007b), suggest that this provides the evidence that fascia contributes to proprioception and nociception. Schleip (2003) argues that fascia is the main organ of perception, providing proprioception, nociception and visceral interoception. Van der Wal (2009) states that fascia has almost 1000% more sensory nerves when compared to muscle including Golgi, Paccini and Ruffini endings.

Also included are a large number of microscopic unmyelinated 'free' nerve endings. These nerve endings are found in a near ubiquitous manner in fascial tissues including periosteum, endomysial and perimysial layers, and in visceral connective tissues. Other researchers confirm that fascia and fascial structures play a significant role in the facility of proprioception (Langevin 2006; Benjamin 2009). Fascial components such as membranes, septa, deep and superficial fascia are supplied with ample proprioceptors to suggest it is functionally important in proprioception (Wood Jones 1946; Standing 2008).

Van der Wal (2009) argues that rather than being due to its topography the ability of the fascial structures to provide centripetal mechanoreceptive information is due to its structural and architectural relationship with musculoskeletal tissue. Stecco et al (2008) consider the tensional forces transferred to the fascial expansions and tendons and the possible effects on proprioceptors. In this way forces are spread across a wide area in several directions providing the necessary feedback via proprioception for economical and efficient movement at local and more distant sites. Van der Wal's (2009) research highlights the activity and role of the mechanoreceptor. Defined not only by its functional properties, but also by its architectural environment. He argues that it is the architecture of the fascial connective tissue in relation to the muscular tissue components and skeletal elements that play a major role in the coding of the proprioceptive information being provided. As already stated fascia architecture has the ability to mediate forces that cause deformation of receptors that are not directly attached to the fascia itself representing the main stimulus for mechanoreceptors, effecting proprioceptive output (Van der Wal, 2009).

Mechanoreceptive information needed for the process of proprioception originates not only from fascia and other connective tissue structures but also from mechanoreceptive or even tactile information from skin, muscles, joint surfaces, and joint structures. Van der Wal's research demonstrates that mechanoreceptors are triggered by mechanical deformation. Proprioceptors monitor timing, intensity, duration and release of tissue deformation in a very precise manner. Myofascial connections provide anatomical continuity linking synergistic muscles to allow reciprocal feedback via multiple pathways, of a mechanical and neural nature, as parts of a specific fascia would be tensioned in a selective manner resulting in a specific pattern of proprioceptive activation (Sharkey 2008).

Stecco (2009) observed that muscle spindles attach to the perimysium suggesting that the spindles are monitoring the connective tissue tension as a primary function. Free nerve endings are, for the most part, nociceptive. Pacinian corpuscles and Golgi organs, which are encapsulated, monitor and respond to local tissue compression as a result of rapid movements and vibration. Encapsulated Ruffini endings, which are only partially encapsulated, respond to changes in axial tension.

Guimberteau et al (2010) has provided the foundation for a new vision of anatomy. This new vision embraces global dynamics and continuous matter (a tissue continuum) and sheds new light on the relationships between the connective tissues of the human body such as dense sheets of muscle coverings, aponeuroses, specific local adaptations including ligaments, tendons, blood vessels, lymphatic's and nerves encased. This and other recent research supports and encourages a more global perspective encouraging surgeons to appreciate that they are working on an organ system and not simply an individual muscle, thus encouraging a sparring approach when incising tissue in an effort to curtail the disruption of the surrounding fascial tissues and architecture of the anatomical location. This new vision calls into question the very foundations of the classical anatomical views held to date and should have a profound impact on current procedures and methodologies for a wide range of surgical procedures and post surgical medical exercise interventions. Guimberteau et al (2010) demonstrated that the continuity of the connective tissue is not interrupted despite distension during sliding or gliding motions. Sharkey (2012) provided a strong visual record of the continuity of the fascia superficialis in Figure 6.

Guimberteau further suggested this network resembled a Tensegrity icosahedron. In the icosahedron the outer shell is under tension. The vertices are held apart by internal compression "struts" that float in the tension network (Levin, 1975). The icosahedron tensegrity is a naturally occurring, completely triangulated, truss that is 3 dimensional (Sharkey, J. 2010 hypothesized that BioTensegrity works on the 4<sup>th</sup> Dimension). BioTensegrity is gravity independent, flexible hinged Omni-directional structure whose mechanical behavior is non linear.



Figure 6. A view of the superficial fascia removed as one autonomous structure. (Sharkey, J. 2013)

In part 2 of this 3 part series:

John Sharkey will discuss BioTensegrity, Four Bar Linkage with Clinical Implications for manual and movement therapies.

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