Mediterranean BioMedical Journals
Integrative Journal of Medical Sciences
2020, Volume 7, ID 260
DOI: 10.15342/ijms.7.260

PERSPECTIVES

Tensegrity Informed Observations in Human Cadaveric Studies A Clinical Anatomists Perspective

John Sharkey MSc
Faculty of Medicine, Dentistry and Clinical Sciences, University of Chester/NTC, Dublin, Ireland

"The whole of the body can be seen in an eye and grasped in a hand. For each limb, one encounters the body as a whole in the part. Therefore, each member is, in the best possible way, that which it is. So, each member is directly the person, and so the whole person is directly in each part." Nikolaus von Kues (1401-1464)

ABSTRACT
19th century anatomy took a systematic, uniform approach as efforts were made to give each anatomical structure a precise description. Concerning red contractile proteins observed within a gastor, descriptive words provided little or no information concerning the anatomy or physiology of such structures. Latin names were provided describing shape (i.e. trapezius), size (i.e. maximus), number (i.e. quadriceps) and anatomical location (i.e. posterior) but did little to inform learners concerning a global view of human form and function. Such a reductionist view concerning muscles was delineated by their assumed tendonous origin/insertion attachment to bone. Bespoke human dissections performed on embalmed cadavers, embracing a (bio)tensegrity focus, provides innovative insights concerning the topics of human anatomy, form and function. Such dissection shifts attention away from the solely mechanistic observations made since the time of Erasistratus (ca. 290 BC) and Giovanni Alfonso Borelli (1608-1679) which led to nebulous interpretations and isolated "parts". Long held concepts such as muscle origins and insertions are not supported as factual evidenced by biotensegrity focused dissections. Borelli's explanations of human movement, based on man-made objects, included wheels, clocks, watches and two-bar pinned joints. Mechanical models require construction materials such as 1st, 2nd and 3rd class levers, pulley systems with pins and screws for functional operation. Embryology does not require surgical intervention to attach an upper or lower limb, a liver, spleen or blood vessel. The embryo grows and develops such structures in a temporal sequalae orchestrated by the forces and the environment wherein it emerges. To-date it has been averred that the human body is a combination of 'parts' comprising of levers and pinned-joints. This observational-based report offers anatomically accurate cadaveric imagery supporting a paradigm shift in human anatomy moving towards a model dependent reality of continuity and wholeness, "Biotensegrity-Anatomy for the 21st century".

KEYWORDS : Biotensegrity, Fascia, biomechanics, embryology, gravity, dissection.

Correspondence: John Sharkey MSc. Faculty of Medicine, Dentistry and Clinical Sciences, University of Chester/NTC, Dublin, Ireland. Email : john.sharkey@ntc.ie

INTRODUCTION

A terse investigation concerning the definition of the word biomechanics reveals similar descriptions with slight variations such as: *"the study of the mechanical laws relating to the movement or structure of living organisms"* and *"the study of the mechanical nature of biological processes, as heart action and muscle movement" (1).* To appreciate the suitability of the word mechanics, specific to human movement, requires an historical etymological account of the birth and development of the term. "Mechanical" derives its meaning from Middle English *"mechanike",* which in turn is derived from the French langue d'oïl "mecanique". Mechanique, in turn, is derived from the Latin "mechanicus" with a specific meaning of *"belonging to machines or mechanics",* from Ancient Greek μηχανικός, "mēkhanikós", *"pertaining to machines"* (2). Man-made constructions work based on the primary force that guided their assembly, gravity. Living forms, or biotensegrities, are self-constructed. Living tensegrities require a distinct set of construction laws and process's free from gravity. Gravity does not play a significant role in the genesis and embryology of living tensegrities. Embryos are the perfect example of a self-evolving, self-assembled construct that organises its own affairs of assembly and organisation (3).

The study of human anatomy and movement can be traced back several thousands of years to the times of the ancient Egyptian's and later to the 16th century explanations of Giovanni Alfonso Borelli. Borelli explained natural movement based on the theories of Galileo (1564-1642) (4). Investigations into Borelli's hypothesis reveals that his model was influenced by the work of Leonardo da Vinci (1452-1519) who was among the first in Europe to accurately dissect human cadavers in staggering detail (5). Following impressive advancements concerning the knowledge of the human body, predicated by the pioneering work of da Vinci, Andreas Vesalius (1514-1564) and others revolutionised anatomy and the study of our human form correcting many misconceptions commonplace in anatomy at that time (6). What we have today is a set of models, theories and explanations best suited to describing the dynamics of two-dimensional man-made constructs, representing individual parts, constructed using hard matter materials (7). Explaining human movement currently embraces words such as "shortening", "lengthening", "stretching", "relaxing" and "contraction" which are deemed inadequate at best and unsuitable at worst (8). The idiosyncratic dissections described in this paper sought to investigate the applicability, relevance and accuracy of basic, underpinning terminology and assumptions such as pin-joints, muscles, levers, stretching, contracting, lengthening. Initial investigation sought to ascertain if the body in death retains the first principle of tensegrity, pre-stress or pre-tension. On initial incision one immediately witnesses the skin and incised subcutaneous tissue receding from the margins. This pre-tension is also seen when an incision is made to the fascia profunda or any fascial tissue deep to the skin (Fig A).

Living tensegrity structures constitute three dimensionally ordered tensional and compressional constructive components providing equilibrium, stability and pre-stress (9). Each component contributes self-pre-tensioned forces aiding and dictating local and global proprioception, physiology and metabolism by means of force distribution through mechanotransductive facilities (10). The forces of tension and compression (epigenetics) support DNA expression (genetics) leading to stiffness, turgor, rigidity and hardness of specific connective tissues (11).

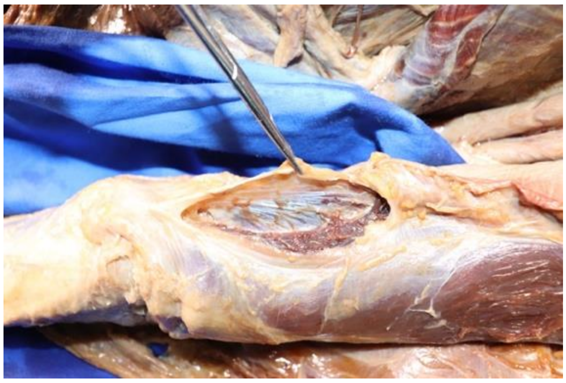

Figure A. Making an incision to superficial or deep connective tissue results in the tissue receding from the margins due to the pre-tension that is present in the cadaver reflecting a first principle of tensegrity structure.

The act of dissecting provides visual evidence that supports a model dependent reality of pre-tension. On dissection the tissues do not remain static but recede, in predominat fashion, laterally to the incision while the tissues are being "pulled" omnidirectionally (Fig A).

The word muscle is derivative of the Latin term mūsculus meaning "little mice", a word stemming from the vocabulary of Galen of Pergamon (A.D.I30-200). Anatomical textbooks refer to muscles having origins and insertions and are depicted as distinct attachments to specific bony locations (11). No such origins and insertions are evident in biotensegrity focused dissections. Alternatively, based on the biotensegrity focused dissection experience bones are best described as floating within a sea of fascial tissue (12). Removal of the fascia surrounding femur and tibia bones allows for the effortless removal of the bones off their associated fibrocartilaginous meniscus tissue (Fig B). The fibrocartilaginous meniscus tissue is in direct continuity with the surrounding deep fascia and capsular densifications of the joint. The periosteum trails continuity with the fascia profunda and outward to the skin by means of the fascia superficialis and the ligamentum cutis (Fig C).

Figure B. Removal of the bony (i.e. osseofascial) element from the fascial tube of the lower limb, within which the femur floats, allows the anatomist a unique perspective of the connected and disconnected qualities and specialities of the fascial net.

Figure C. A transverse dissection midway along the shaft of femur provides a unique view allowing the clinical anatomist to trace the continuity of the fascia superficialis in direct and indirect pathways leading to the fascia profunda terminating as the contiguous encasing periosteum.

According to professor of anatomy Jaap van der Wal it is not possible for all the forearm flexors to attach to the medial epicondyle as described in anatomy text books (12). This view was thoroughly supported during dissection as viewed in figure D1.

Figure D1 and D 2 Image D1 is of the antebrachial fascia of forearm demonstrating the impossible nature of the medial epicondyle of humerus to accommodate tendons of pronator teres, flexor carpi radialis, flexor carpi ulnaris, flexor digitorum superficialis and palmaris longus (not to mention the need for additional space to accommodate the ulnar collateral ligament).

Image *D2* Using a digital calibre and a soft cloth measuring tape measurements were taken on regular intervals during flexion and extension to note any changes in length of the structure being measured.

According to the Oxford English Dictionary the term contraction means " to draw together "or "to shrink". While the term contraction may be considered constructive in describing the concentric phase of a muscle contraction it fails in describing the eccentric or so-called lengthening phase. To investigate the premiss that tissues shorten or lengthen during the positive and negative phase of movement required the use of digital calibre's and a soft cloth measuring tape (Fig 2). Specific anatomical points were chosen, not only tendons, and repeated measurements were taken at 10 degree intervals. In the case of the image provided (D1) Lacertus fibrosis and the entire biceps brachii muscle were measured tendon to tendon for length changes.

While shape changes were noted at no stage did the length of the tissue being measured change throughout flexion or extension. This fits well with tensegrity principles as any slack in the system would be akin to slack spokes in a bicycle wheel.

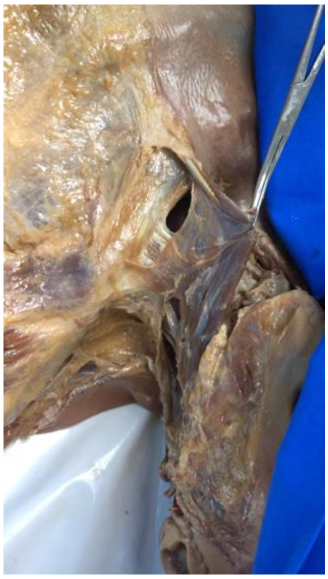

Figure E This image of the so-called insertion of *Sternocleidomastoid* (SCM) is typical of what was found in dissection concerning all muscles. No specific insertion point or point of origin could be identified. SCM and its associated fascia continued inferiorly along the sternum. In this way bones float within the sea of fascia. (Image: Head at bottom right side, cadaver supine).

Figure F is an example of bi-lamina sheaths of fibrous and loose connective tissue constructed in a convoluted or corrugated manner facilitating lengthening forces without resulting in a stretch to the neurovascular bundles contained within. Many research papers refer to stretch receptors as connective tissue is constructed to resist stretching via activity of muscle spindles. This in effect means that attempting to lengthen connective tissues results in a contraction of the targeted tissues (13). Essentially, any attempt to lengthen a tissue results in an equal and opposite "contraction" (i.e. reaction) in an effort to avoid being stretched. This is a result of mono-synaptic reflex or myotatic reflex arc. The word 'stretch' is a word who's etymology traces back to the 14th century with the specific meaning: *'to lengthen by force or enlarge beyond proper limits, exaggerate'* (14).

Figure F. This image provides an example of bi-lamina sheaths of fibrous and loose connective tissue constructed in a convoluted manner facilitating lengthening forces without causing a stretch to the neurovascular bundles contained within.

Multiple knee joints were placed in positions at angles greater than 90-degrees for the images in Figure G1, G2 and G3. The cruciate ligaments are dense bands of connect tissues rich in collagens, neural structures and mechanosensing receptors (15). During the biotensegrity focused dissections the anatomical position of these ligaments clearly identified them as intra-articular structures. Observations made during passive flexion and extension of the joint highlighted that the cruciate ligaments remained actively engaged throughout both phases without any noticeable change in length.
This observation of continuous tension through the full range of motion is in keeping with the findings of professor of anatomy Jaap van der Wal (12). Fig G1shows the helical four-bar closed kinematic chain arrangement of the cruciate ligaments.

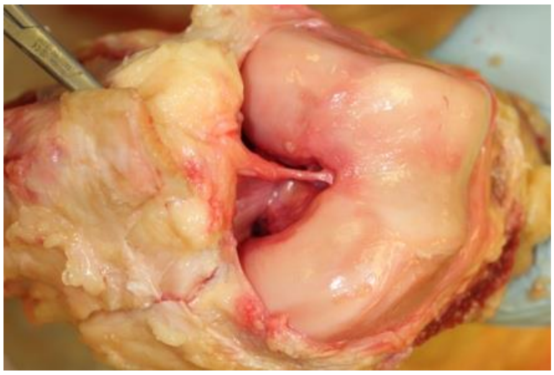

Figure G1 and G2 and G3. Anatomical investigations show the helical four-bar closed kinematic chain arrangement of the cruciate ligaments of the knee.

Tubes within tubes

Tube-like structures are evident throughout the human body including blood vessels, lymphatic tissues, neural structures, myofibers, collagens, bronchus, dura, intestines, trachea, oesophagus, ureters, bladder (8). Removing the Quadriceps as one autonomous structure supports the opportunity to appreciate the concept of a "tubes within tubes" analogy. Encapsulating the entire Quadriceps complex we see the most superficial aspect of the fascia profunda with its helical, chiral collagen with tubular fiber arrangement (Fig H). On closer inspection one can see the helical tubular content of nerves, blood vessels, muscle fibers and indeed the entire content enclosed within a fascial tube in and of itself (7). This view of the quadriceps is in contrast to how anatomy text books typically display the muscles looking from behind as opposed to the anterior perspective. Much can be learned by taking an inside-out approach providing the foundation for a more fascia based wholistic oriented discussion.

Figure H. Removing the Quadriceps as one autonomous structure supports the opportunity to appreciate the concept of the "tubes within tubes" analogy. Encapsulating the entire Quadriceps complex we see the most superficial aspect of the fascia profunda with its helical, chiral collagen fiber arrangement. The chirality of the fascial condensations are clearly visible. The inter-play of these fascial thickenings contribute to local and global requirements responding in a temporal specific manner.

CONCLUSION

This short report aims to encourage additional research investigating the validity of long held ambiquous preconceptions within clinical anatomy and physiology. Concepts are important. The language and vocabulary supporting the explanations underlying concepts are equally as important. Currently in anatomical study (and physiology) we are using inadequate, even misleading, terms, language and explanations words such as 'stretch', 'contract', 'attach', 'origin' and 'insertion'. This paper calls for a move towards investigating and agreeing a new nomenclature that embraces an up-to-date 21st century view of human form and function. Words have meaning and meanings are critical for ensuring cross pollination across disparate scientific disciplines.

ALL IMAGES

Sharkey J. 2020

AUTHOR DECLARATION CONCERNING CONFLICT OF INTEREST

No conflict of interest.

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