Continuous Tension, Discontinuous Compression

A Model For Biomechanical Support Of The Body©

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The following is the text of an address made before the North American Academy of Manipulative Medicine in 1980. Since then, refined editions have been presented to the following: Medical College of Virginia, Anatomy Department of Howard University, The Paleontology Society of the Smithsonian Institution, the Alliance for Engineering in Biology and Medicine (fall, 1981). Presentation to the International Society for the Study of the Lumbar Spine in Toronto is scheduled for June, 1982.

Man's concepts of engineering and the subcategory, Bioengineering, are rooted in the Egyptian, Greek and Roman concepts of engineering and architecture, fighting the compressive forces of gravity with columns and massive blocks of stone.

It is only in recent history when we have developed newer materials that we have recognized that tension forces can play a significant role in the integrity of structures. However, engineers use tension mainly as a support system for compression loads. In humans, McNab[7], Farfan[1], White[13] and others recognize that tensional components of muscles and ligaments probably play a role in spinal support, but only Kirkby[6], and Robbie[11] felt that at times tension may be the major support force of the spine. Robbie[11], however, still believes that the spinal column is capable of functioning only as a "stack of blocks" and Kirkby[6] feels that only when the body is properly "balanced" in the gravitational field does tension function as the major support.

It is the author's contention that only in failure does the spinal column function as a "stack of blocks." The support system of the spine, and indeed the remainder of the body as well, is a function of continuous tension, discontinuous compression, so that the skeleton, rather than being a frame of support to which the muscles and ligaments and tendons attach, has to be considered as compression components suspended within a continuous tension network.

Since the spine is a mechanical structure, investigators have used mechanical models to attempt to study spinal kinematics and kinetics. Until now, all models, mathematical or actual, have been based on the axial-loaded compression support system. The problem of such a construct is that they are unidirectional, so that, like a "stack of blocks," or the Great Pyramid, they would be pulled apart by the very forces that were conscripted to hold them together if tilted out of plumb. The mechanical laws of leverage that operate in the compressional system would create forces that far outstrip any strength of biologic materials. We could not use such a system to walk on our two legs, crawl on all fours, walk on our hands or stand on our heads without the addition of tensional forces to hold us together. Such a system is only as strong as its weakest link.

The structural system of continuous tension, discontinuous compression, hereafter referred to as Tensegrity, and described by Buckminster Fuller[2], can be used as a model to understand the physiological support systems of the body.

The understanding of tensegrity structures has many distinct advantages when applied to biological systems. These structures are omnidirectional and are stable in any direction and independent of gravity. When applied to animated beings the structural system is maintained whether functioning as a biped or quadriped; prone, supine or standing upside down; on the ground, under water or in a spaceship. The laws of leverage act differently when applied within the tensegrity system so that forces generated are dissipated and may actually strengthen the structure—much as prestressed concrete or a wire under tension. External forces applied to the system are dissipated throughout it so that the "weak link" is protected. The forces generated at heelstrike as a 200 pound linebacker runs down the field, for example, could not be absorbed solely by the *os calcis* but have to be distributed—shock absorber-like—throughout the body.

Does the tensegrity system function in nature? The methane molecule, one of the most basic organic substances, has in itself the physical shape and properties of a tensegrity structure. Examination of radiolaria clearly demonstrates the basic structural model. In higher forms of life, we can examine the scapulothoracic articulation. The entire support system of the upper extremity is a tension system being supported by the musculature interweaving the spine, thorax and upper extremity into a tension support system. The scapula does not press on the thorax. The clavicle has been traditionally recognized as acting more as a compression strut, as it would in a tensegrity model. In fact, in the cat family it is no more than a floating tensegrity strut. Although in humans the upper extremity is not weight-bearing, if we recognize that the same mechanism is used in bearing weight in all quadripeds, then we can readily see that the tension support system is utilized in vertebrates.

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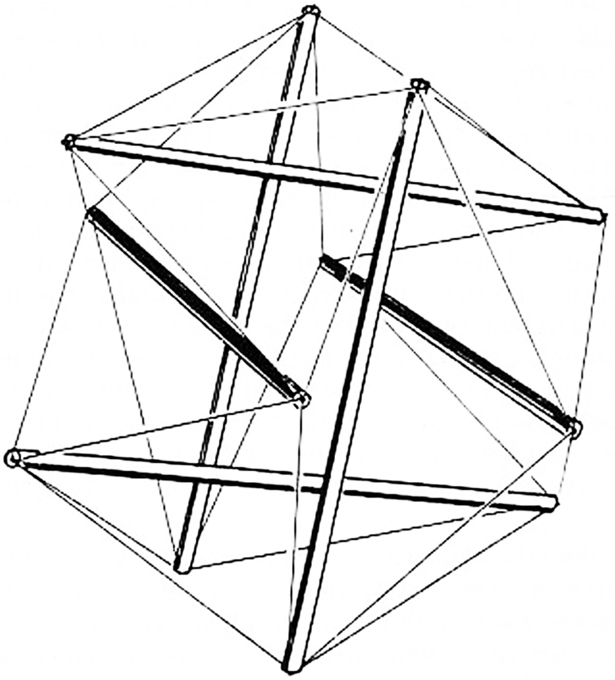
The anatomist Grant[3], in his classic book *Methods of Anatomy* describes the sacroiliac joint, the major supporting joint between the pelvis and spine and its superimposed structures. He states that the sacrum behaves not as a keystone but as the reverse of a keystone, and tends, therefore, to sink forward into the pelvis. The spine and its superimposed structures are, of course, supported by the massive ligaments so that the sacrum—and all that is above it—is "slung" in the pelvis and not dependent on axial-compressive support.

We therefore can see in readily discernible anatomical studies that the tensegrity system is utilized in two of the major support joints of the body, the scapulothoracic and the sacroiliac joints. Tension functions not as a support to a compressive system, but rather as the only system in support of these joints.

Let us build a tensegrity model in its simplest form, the icosahedron. (Figure 1.) The mechanical properties are described by Fuller.[2] First, it is omnisymmetrical, one of only five omnisymmetrical objects that can be constructed in space. Only three of these are structurally stable, the tetrahedron, the octahedron and the icosahedron. The icosahedron is structurally the most economical, containing the most volume for surface area. It is constructed of six struts and twenty triangles. It is the basic building block of tensegrity structures, and they can be combined in periodic arrays to create towers or structures of infinite sizes and shapes, all units being integrated with one another. Second, the structure does not behave in the way we expect most solid constructed structures to behave. If two opposite and parallel struts are pushed or pulled, all six members will move inwardly or outwardly, causing the icosahedron to contract or expand in a symmetrical fashion. These compression members do not behave like conventional engineering beams. Ordinary beams deflect locally, tending to contract the building in axial asymmetry. The tensegrity beam does not act independently but acts only in concert with the whole building, contracting symmetrically when the beam is loaded.



Stated simply, the whole structure compresses when under pressure from outside, and rotates slightly, resembling the coupled motion in the spine as described by Panjabi[16]. Because a tensegrity structure contracts symmetrically, the parts move symmetrically closer to one another. Therefore, gravity increases to the second power and the whole system gets uniformly stronger. We thus have a system that is omnidirectional, symmetrically compressible and expandable, and local-load distributing, like soccer balls and auto tires.

What about the biomechanical studies that have amassed over the years? They have all been based on the assumption, a point never proven, that the body is an axial-loaded, compression resisting structure. One of the principles of tensegrity is *Synergy*, defined by Fuller[2] as the behavior of integral, aggregate whole systems unpredicted by behaviors of any of their components or subassemblies of their components taken separately from the whole. For example, one would not examine the properties of the metal sodium, and the gas chlorine, and predict the properties of the combination, salt. Tensegrity structures have the property of synergy. Therefore, any studies of subassemblies of vertebrae, discs, ligaments, motion segments and the like, have to be reassessed. Nachemson[8], in outstanding studies with transducers placed in discs of live subjects, does not show compressive loads, but only pressure on the transducer which could be transmitted by compression, shear, or tension.

There is a corollary to the concept of synergy known as the Principle of the Whole System, which states that the known behavior of some of the parts make possible the discovery of the presence of other parts and their behaviors, kinetics, structures, and relative dimensionalities.

We should, therefore, be able to predict behavior of certain structures, and make the following assertions:

1. Ligaments are under continuous tension.

Studies by Nachemson[9], Tkaczuk[12], Kazarian[4] and others have shown what is described as "pretension," indicating that the ligamentum flavum, anterior longitudinal ligament, and posterior longitudinal ligament are under tension when the spine is in a neutral position. At no time are these ligaments completely lax, indicating a continuous tension state. Kazarian[4] describes that when the vertebral bodies are held together only by the intervertebral discs, after having cut the anterior and posterior longitudinal ligaments, the vertebral column expands, as would be expected in a tensegrity system if some of the tension members are cut.

We must recognize that all muscles attached to the spine have a physiologic resting length, which means that they are under continuous tension, never becoming completely lax. They, therefore, contribute to the continuous tension system as well.

It has been assumed that a ligament may support a load but it cannot move the load. This is not entirely true as the ligaments do act as rubber bands, and when they are deformed, tend to return to their resting length. When energy is imparted into the system by muscular action, or for that matter, by any other force, and the ligaments are stretched, they will absorb these forces, contract, and then move the load. Ligaments under tension would therefore act as "movers" if their tension were not restrained by an equal and opposite force. The ligamentum flavum has the highest percentage of elastic fiber of any tissue in the body and, therefore, must do quite a bit of stretching and contracting.

2. Certain structural configurations can be predicted.

Tensegrity structures use 60 degree coordination instead of 90 degree coordination. Kazarian[4] points out that the assumed 90 degree transmission of forces is wrong and a more acute angle of force should be used.

Anatomical studies of the fibers of the annulus of the disc show that they are 60-degree oriented.[13]

The relationship of the superior compressive member to the inferior compressive member in a tensegrity unit is such that an element of the superior member is inferior to the superior-most element of the inferior compressive member. (Figure 1.) This relationship continues to exist even if the structure is rotated in any position, as it is omnidirectional. This spatial relationship can be seen to exist in the vertebral column and, indeed, in essentially all the synovial joints in the body.

3. Although some of the rigid components of a tensegrity system may "kiss," it does not mean that they are in compressive opposition to one another. Axial loads were applied to joints in live subjects under anesthesia during surgical intervention for a variety of conditions. Joint studies included the knee, ankle, elbow and metatarsal-phalangal joints. In our studies at no time could the articular surfaces of these joints be forced into contact with one another as long as the ligaments remained intact. Although the study may lack elements of sophistication, it is readily reproducible by any surgeon.

Conclusion: A rigid, axial-loading, gravitationally-oriented support system cannot be utilized as a model for animated structures, including the human spine. A model based on Buckminster Fuller's[2] tensegrity icosahedron , which demonstrates the principle of continuous tension, discontinuous compression, may also be utilized to demonstrate the structural integration of the body. All our previous concepts of biomechanics of the body will have to be reassessed in relation to this model and our therapeutic approaches to the musculo-skeletal system will have to be revised.

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