Tensional Forces in the Human Body

Understanding Rolfing & Gravity

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Most analyses of the manner in which the human body holds itself up have focused on the hard elements of the body, the bones. In so doing, they have looked mainly at compressional forces in the body and at how the skeletal structures withstand these forces. Some mention of tensional forces is made in kinesiology textbooks in reference to the role of "postural muscles." But tensional forces have generally been regarded as of secondary importance in maintaining the structural integrity of our upright bodies.

My purpose in writing this paper is to discuss some new ways of looking at the human body in terms of tensional forces. We now have a model - Buckminster Fuller's tensegrity mast[1,2] - which permits us to better understand and appreciate the crucial importance of tensional forces in maintaining the structural integrity of our bodies. This paper will attempt to analyze the structure of the body in terms of this model in order to understand the role that tensional forces play in maintaining our upright posture with greater precision.

Spinal Column Core Structure

Any attempt to analyze "how the human body holds itself up" must, necessarily, deal with the spinal column, which is the core structure of the trunk and a major structural element of the body. In our upright position, the weight of the head, arms and trunk is supported by the spinal column. Anatomists and kinesiologists have long viewed the spinal column as a stack of blocks, mostly because stacked vertebral bodies look like a stack of blocks.

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They have concluded that the weight of the upper body is supported by the spinal column as if it were such a stack. In short, they have seen the spinal column as a purely compressional structure - a stack of hard blocks (the vertebral bodies) separated by soft cushions (the intervertebral disks).

Kirkby[3] has proposed Buckminster Fuller's tensegrity mast as a new model for the structure and function of the spinal column. This model differs significantly from the traditional stack-of blocks model. In a tensegrity mast, weight is borne by a balance between tensional and compressional forces, in sharp contrast to the purely compressional nature of a stack of blocks. To determine whether the spinal column is more accurately represented by a stack of blocks or a tensegrity mast, we must carefully examine it.

There is ample evidence that the spinal column often functions compressionally, like a stack of blocks. People with back disorders often end up with crushed, wedge-shaped vertebral bodies, or herniated intervertebral disks are subjected to great compressive loads. So the spinal column in many people does function as a stack of blocks. But is this the only way the spinal column can function? And is it designed to function optimally as a stack of blocks?

Look at a Lumbar Vertebra

A look at the internal architecture of a lumbar vertebra yields some startling information that sheds light on the above questions. If the spinal column were to function solely as a stack of blocks, then a lumbar vertebral body would have to bear the weight of the entire trunk, as well as any additional weight carried by the person. To do this, it would have to be a strong weight-bearing structure. If it were a strong weight-bearing structure, it would have a thick layer of compact bone or it would have vertical stress lines observable in the trabeculae of its cancellous bone. One or both of these features are present in all the weight- bearing bones of the body, including the sacrum, pelvis, femur, tibia, talus and calcaneous.[4] But neither feature is present in any of the vertebral bodies, including those of the lumbar vertebrae.

When we look at a lumbar vertebra, we see that the vertebral body is made up almost entirely of cancellous or spongy bone with no trabecular stress lines and only a thin layer of compact bone.[5] A lumbar vertebral body simply doesn't look like a weight-bearing structure in the way a femur looks like a weight-bearing structure, for example. It doesn't look like it is capable of bearing the weight of the trunk of the body plus the 100 or more pounds a person might lift.

Perhaps the vertebral bodies were never meant to bear the entire weight of the trunk. Perhaps the wedging of the vertebral bodies so commonly seen in back disorders is evidence of what happens when the spinal column functions too much like a stack of blocks. It just may be that the spinal column is not designed to function optimally as a stack of blocks.

How Then Is Weight Borne?

But if the weight is not borne by the vertebral bodies, how is it borne? Another look at a lumbar vertebra suggests the answer. While the vertebral body has only a thin layer of compact bone, the entire neural arch structure, including the superior and inferior articular processes, contains a thick layer of compact bone.[5] The neural arch looks like a structure that is designed to bear a substantial compressive load. A vertebra, then, seems to be designed to bear a compressive load in the neural arch rather than in the vertebral body.

But if the weight is borne in the neural arch of an individual vertebra, how is the weight borne by the spinal column as a whole? In other words, how is the compressive load transmitted from one neural arch to the next lowest neural arch?

It is obvious that this is not accomplished by a simple stacking of blocks, because the planes of the joints between two neural arches are so vertically oriented that the higher vertebra would simply slide down on top of the lower vertebra.

A look at the way two lumbar vertebrae fit together suggests an answer. Each vertebra contains a pair of upward projecting superior articular processes and a pair of downward projecting inferior articular processes. When two lumbar vertebrae - say L-1 and L-2 - are articulated, the upper tips of the superior articular processes of L-2 are situated higher than the lower tips of the inferior articular processes of L- l.

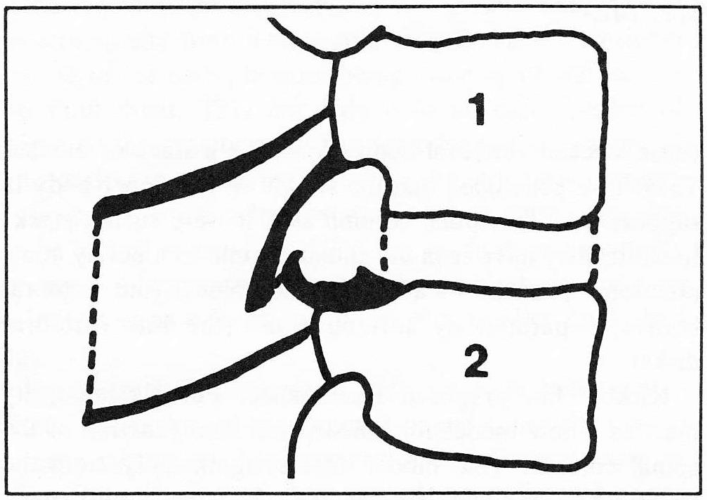

Fig 1. *This linear diagram illustrates how vertebral body 1 is suspended over vertebral body 2 by the tensional properties of the connective tissue as opposed to the compressional properties of the vertebral bodies.*

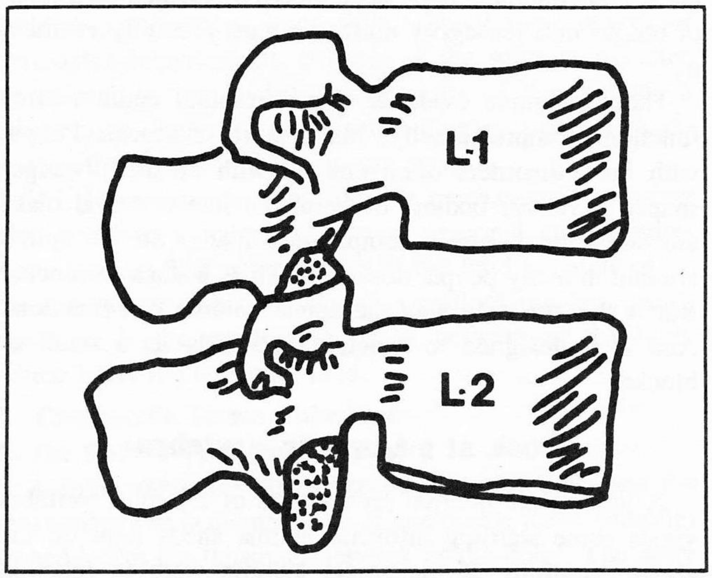

Fig 2. *This is an actual drawing of L-1 and L-2, showing the relationship of the inferior articular process of L-1 below the superior articular process of L-2.*

These two pairs of articular processes are the bony components of the two intervertebral joints between L- I and L-2. Each joint is encapsulated and held together by fibrous connective tissue. This connective tissue could keep a vertebra from sliding down on top of the next lowest vertebra by means of a tensional rather than a compressional force. In other words, it is conceivable that this connective tissue could act as a sling. The two inferior articular processes of L-l would then be supported by tensional members suspended from the superior articular processes of L-2.

The accompanying schematic diagrams of an intervertebral joint between the first and second lumbar vertebrae illustrate the relationships involved (Figs 1,2). Note that the upper tip of the superior articular process of L-2 is situated higher than the lower tip of the inferior articular process of L-1. Note that the connective tissue forms a sling by which the inferior articular process of L-l is suspended from the superior articular process of L-2. If we now expand our view to include both intervertebral joints between L-l and L-2, we see that the weight of L-l is being supported by L-2 by means of a tensional rather than a compressional force.

A Tensegrity Mast

Our spinal column is now beginning to look suspiciously like a tensegrity mast (Fig 3). The paired superior and inferior articular processes of each vertebra are analogous to the paired upward projecting and downward projecting struts of a compression unit in a tensegrity mast.

And the slings of connective tissue – by which the weight of one vertebra is supported tensionally by the next lowest vertebra – are analogous to the almost horizontal strings in a tensegrity mast. These almost horizontal strings in the mast form a sling by which a given compression unit is sup- ported by the next lowest compression unit.

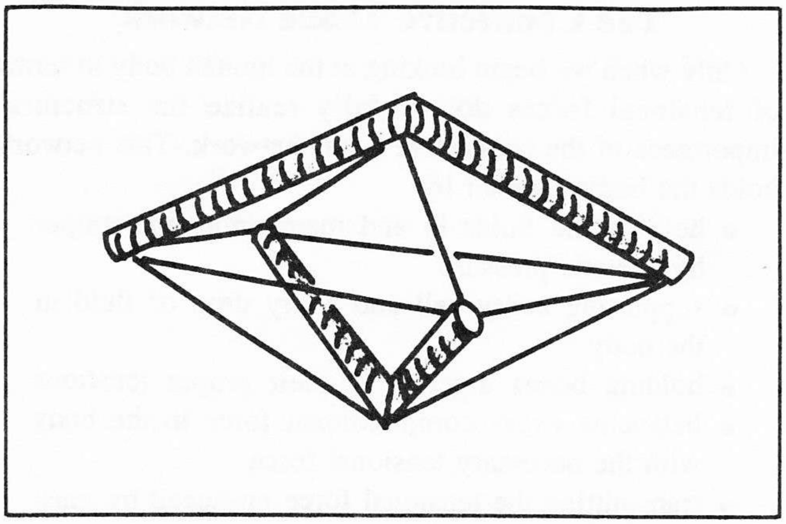

Fig 3. *A basic cell from a tensegrity mast shown here illustrates the principle of how two solids (compression elements) are stacked one on top of the other and held in place by means of the tension in the tensional elements.*

The spinal column has many other myofascial connections besides the connective tissue around the intervertebral joints. Many of these are vertically oriented and probably act mainly to balance and stabilize the spinal column. They include the interspinous ligaments, the anterior and posterior longitudinal ligaments and the intertransverse ligaments and muscles. These structures are analogous to the vertically oriented strings in a tensegrity mast, which function mainly to balance and stabilize the mast.

Let us now look at the entire spinal column with all its myofascial connections. We see vertebral bodies and inter- vertebral disks, which appear to be capable of supporting a certain amount of weight compressionally.

But we also see neural arches, which have thicker layers of compact bone than the corresponding vertebral bodies and thus seem capable of supporting even more weight than the vertebral bodies. And we see that there are myofascial connections between adjacent neural arches that seem to be capable of supporting weight tensionally and transmitting weight from one neural arch to the next tensionally. Finally, we see that the vertebrae are enmeshed in a complex web of myofascial tissue. This web contains elements that are sling-like, as well as elements that arc vertically oriented. In this regard, it again bears a striking resemblance to the web of strings of a tensegrity mast.

Spinal Function in Two Modes

The spinal column is quite capable of functioning as a stack of blocks. It also appears to be capable of functioning as a tensegrity mast. Perhaps it always functions in both modes. The fact that people with back disorders develop wedge-shaped vertebral bodies and herniated intervertebral disks indicates that too much dependence on the stack-of-blocks mode is not the optimal way of using the spinal column. The spinal column seems to function more effectively if a substantial part of the weight of the body is supported by the tensegrity mast consisting of the neural arches and their myofascial connections.

It must be remembered that both the stack of blocks and the tensegrity mast are only approximations that help us understand the structure and function of the spinal column. In actuality, the spinal column is far more complex than either metaphor. In point of fact, the spinal column is in- separable from the rest of the body and must be understood in that context.

The value of the tensegrity model consists in demonstrating that a complex structure is capable of bearing weight by means of a balance between tensional and compressional forces. This model applies even when the structure in question is composed of both hard and soft segments, vertical or nonvertical.

When we look at the human body with this idea in mind, we begin to notice how much we rely on tensional forces to remain upright.

A man standing with his knees bent forward is obviously relying on tensional forces to keep his legs from collapsing under him. It is not so obvious, but equally true, that a man standing with his knees straight is also relying on tensional forces to keep his legs from collapsing. It is even less obvious, but again equally true, that he is also relying on tensional forces to keep his spinal column from collapsing. There is no way you can make an isolated skeleton or spinal column stand on its own, even if you include the intervertebral disks. The tensional members of the human body are totally necessary for its structural integrity and its ability to remain upright.

Structural Differences

If we now look at the human body to see how it differs structurally from a tensegrity mast, we notice three important differences.

1. The Tensional Units of a Tensegrity Mast Are All Lines

The first of these differences is that in a tensegrity mast, the tensional units are all lines, whereas in the human body the tensional units are generally arranged in sheets – they are surfaces rather than simple lines. In the biologic organism, these units are specifically the layers of fascia that envelop all the muscles, organs and even the bones of the body. Thus the tensional network of the human body is a network of sheets rather than lines. This network has two noteworthy qualities: its unity and, simultaneously, its complexity. The connective tissue network of the body is literally all one piece; it is a single, continuous organ. Be- cause of this quality, the tendon of a muscle, for example, is continuous-with the periosteum of the bone to which it attaches and, by such continuity, with the connective tissue of every other muscle and bone in the body.

The connective tissue network is also complex. In addition to enveloping every muscle, organ and bone in the body, the connective tissue ramifies within each muscle, organ and bone, forming a supporting network all the way down to the cellular, microscopic level. If you were to remove everything but the connective tissue from a body, you would see a perfect and detailed outline of the body.

2. **The Tensional Network Besides Its Surfaces Is Also Fluid-Filled**

The second important way in which the human body differs structurally from a tensegrity mast is that the tensional network of the body, besides being made up of surfaces, is also fluid filled. This not only adds an extra burden of weight to the structure, it also introduces the element of hydrostatic forces playing a part in the structural integrity of the body. From a hydrostatic point of view, a muscle can be looked at as a fluid-filled bag made of an essentially nondistensible material (fascia). The whole body can then be looked at as a large bag filled with smaller fluid-filled bags.

The hydrostatic pressure of such a system and the non- distensible quality of the material would cause the system to resist significant displacement of any element, hard or soft, within the system. Any hard elements (bones) placed within such a system and firmly secured to various of the inner bags would then be supported in part by hydrostatic forces. The hydrostatic forces would resist horizontal displacement. Since in the case of a lumbar vertebra, downward displacement is impossible without some degree of horizontal displacement, collapse of the spine would then be resisted by the hydrostatic integrity of the system. It seems quite likely that such factors do play a part in maintaining the integrity of the human spine.

It is interesting to note that this mechanism of support also involves a balance between tensional and compressional forces: The compression of the fluid is balanced by the tension on the nondistensible wall of the bag. And, again, it is the connective tissue network of the body which bears the tensional load.

3**. Contractile Tissue Imbedded in the Body's Tensional Network**

A third important difference between the body and the tensegrity mast is the presence of contractile tissue (muscle) imbedded in the tensional network of the body. The body is thus capable of causing continuous complex changes in the relative length and tension of the various parts of its tensional network. It is dynamic rather than static.

The Connective Tissue Network

Only when we begin looking at the human body in terms of tensional forces do we fully realize the structural importance of the connective tissue network. This network holds the body together by

- holding the fluids in and maintaining the proper hydrostatic pressure
- supporting every cell and every drop of fluid in the body
- holding bones together in their proper locations o balancing every compressional force in the body
- with the necessary tensional force
- transmitting the tensional force produced by muscle contraction to the appropriate place

It even transmits weight from one bone to another and thus helps to carry the weight of the body. In short, the connective tissue network is the organ of tensional support of the body. It is the necessary complement to the skeleton, the organ of compressional support. To perform all these functions optimally, the connective tissue network must be appropriately proportioned, sufficiently resilient and of proper length and tension throughout. If it is too tight or short in certain places, it can compress various segments of the body together. It can, for example, keep the spine compressed and, therefore, keep it functioning more like a purely compressional structure.

Fortunately, the connective tissue of the body has a certain amount of plasticity. Ida P. Rolf, PhD, has devised a system of connective tissue manipulation that takes advantage of this plasticity. In her system, called structural integration or Rolfing, the connective tissue is thoroughly and systematically manipulated in a series of l0 sessions. The purpose of such manipulation is to release the places where the connective tissue is too short, tight or adherent and to thereby allow the spine to elongate and begin to function more like a tensegrity mast. Much of the compression in the lumbar spine and the symptoms thereof are relieved. This author's clinical observation is that after Rolfing, the body becomes longer, straighter, better proportioned and balanced.

It is contended that the connective tissue network – having been freed to more optimally perform its indispensable functions – promotes entire body benefits in reduced tension, greater ease of movement, better fluid flow and more optimal health.

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