The Mechanics of Martial Arts

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The symbol of strength for western culture is the Greek god, Atlas. After a mythical war between the Olympians and Titans, Atlas, one of the losers, was condemned to stand as a pillar and support the universe on his shoulders for all eternity (Figure 1).

Figure 1. Atlas holding the world

Following this model, strength, in western thought, is characterized as a rigid, unyielding and unmovable column. Western thought has the rigid column, the lever, and brute force, all concepts familiar to us since childhood when we built our first stack of blocks, rode a seesaw and smashed our first toy. In eastern thought, strength comes from deep within and is flexible, yielding and mobile; it flows. This difference in philosophy of strength is expressed in a difference in approach to combat sports. But eastern philosophy has not had a physical model for martial arts that a western trained mind could wrap a thought around. That is, not until biotensegrity.

Biotensegrity is a mechanical model of biologic structure and function based on construction concepts introduced by Kenneth Snelson and Buckminster Fuller in the 1960's. In these models, the compression struts or rods are enmeshed and 'float' in a structured network of continuously connected tension 'tendons' (Figure 2). The shafts constructed by tensegrity networks are as different from a conventional column as a wagon wheel differs from a wire spoke bicycle wheel. Let me explain.


Figure 2. Needle Tower, Snelson, Hirsshorn Museum, washington, DC. The compression spokes 'float' in a tension network.

A conventional column is vertically oriented, compression load resisting and immobile. It depends on gravity to hold it together. It can only function on land, in a gravity field. The heavy load above fixes it in place. It must have ground beneath it for support. The weight above crushes down on the support below and the bottom blocks must be thicker and stronger than what is above it.

If the spine is a conventional column, the arms and legs will cantilever off the body like flagpoles off a building. Moving an up-right, multiply hinged, flexible column, such as the spine as envisioned in conventional biomechanics, is more challenging than moving an upright Titan missile to its launch pad. Walking and running have been described as a 'controlled fall', a rather inelegant way to conceptualize movement. It certainly doesn't describe the movement of a basketball player, a ballet dancer or a martial arts master. In the standard spine – column model, the model for mobilizing the spine and putting the body in motion would be a wagon wheel (Figure 3 A).

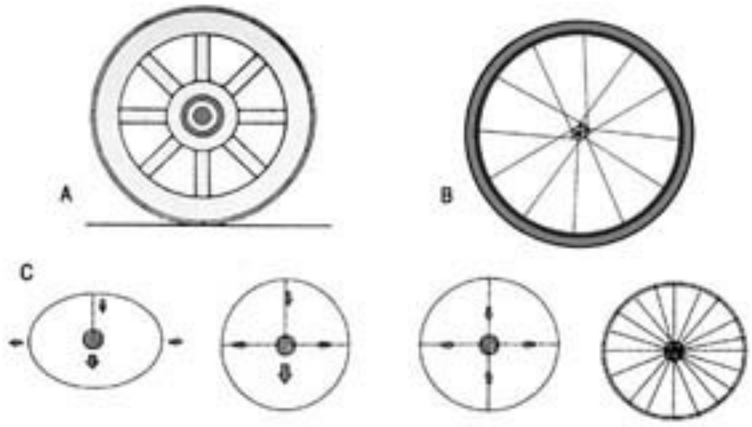

Figure 3. A. Wagon wheel. The compression spokes are thick and short. The rim is thick and heavy. The load vaults fro m one spoke to the next as the wheel rotates. B. Wire bicycle wheel. Long, thin tension spokes. The rim is thin and light. C. In a wire wheel, the hub is suspended by a tension spoke (a). It will belly out if not contrained by other tension spokes (b). Additional spokes distribute the load (c, d).

In a wagon wheel, each spoke, compressed between the heavy rim and the axle, acts as a column. The wheel vaults from one spoke/column to the next, loading and unloading each spoke in turn. The weight of the wagon compresses the single spoke that then squeezes the rim between the spoke and the ground. At any one time, only one spoke is loaded and the other spokes just stand there and wait their turn. The spoke must be rigid and strong enough to withstand the heavy compression load and short, thick spokes do better than long, thin ones. The rim must be thick and strong, as it would crush under heavy load as it, too, is locally loaded. The forces are generated from the outside to the center. Using the column, post and lintel model, in a standing body, the heel bone would have to be the strongest bone in the body instead of, as it is in life, one of the weakest and softest.

Biotensegrity bodies would be like a wire-spoke bicycle wheel (Figure 3B). In a wire wheel, the hub hangs from the rim by a thin, flexible spoke. The rim would then belly out if it were not for the other spokes that pull in toward the hub (Figure 3C). In this way, the load is carried by the tension of the many spokes, not the compression strength of one. The load gets distributed through the system and the hub is floating in a tension network like a fly caught in a spider web. All spokes are under tension all the time, doing their share to carry the load. They can be long and thin. Even loads at the rim become distributed through the system so the rim does not have to be thick and strong as in a wagon wheel (Figure 3A). The structure is omni-directional and functions independent of gravity. Unlike a conventional column, it is structurally stable and functional right side up, upside down or sideways. A tensegrity structure can function equally well on land, at sea, in air or space.

Now think of each cell in the body behaving structurally as if it were a three-dimensional bicycle wheel. Each wheel would connect to each adjacent wheel the cell level, up the scale to tissue, organ and organism, a wheel within a wheel within a wheel. In this system all connective tissues in the body work together, all the time. It known, by recent experimental work that all the connective tissue, muscles, tendons ligaments right down to the cells are interconnected in just this way (Figure 5).

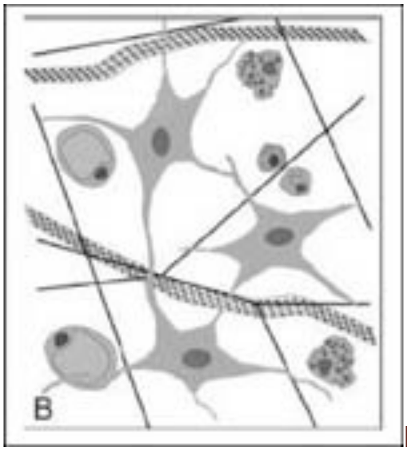

Figure 5. Interconnected Fibroblasts (Courtesy H. Langevin)

The body model would be more like Snelson's 'Needle Tower' (Figure 2) where the 'bones' of the tower are enmeshed in the wire 'tendons', never touching or compressing one another. Unlike flagpoles attached to the side of a building, the limbs are integrated into the system. The energy flows from deep within the structure, chi, out to the tips of the fingers and toes.

The basic building block of the biotensegrity structures, the finite element, is the tensegrity icosahedron (Figure 6).

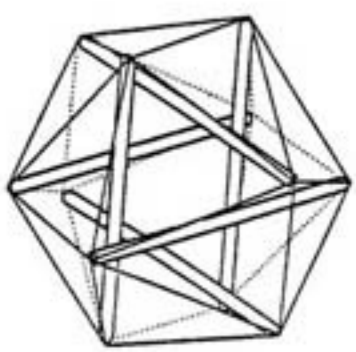

Figure 6. Tensegrity icosahedron

We needn't go in to all the details of the evolution of the biologic body here, but there are some very special properties of the icosahedron that explain the particular characteristics of biologic structure. It is, mathematically, the most symmetrical structure and, in its resting state, is extremely energy efficient. Distorting the shape requires energy and when that energy is released, it returns to its least energy state, a, normally, self-regulating and self-generating mechanism. It is like a spring that, when distorted, will bounce back to its original shape. But it is a very special spring. When a steel spring is in its resting state, there is no energy storage. Adding a weight, say a kilo, will stretch the spring a defined amount, say 10cm. Each additional kilo will stretch the spring an additional 10cm. When the spring is released, all the stored energy is immediately released and the spring will snap back. If it is not restrained, it will bounce because of the accelerated motion. And, depending on how springy (elastic) it is, it will bounce and bounce and bounce, jerking up and down. This is the type of spring associated with the standard column, post and lintel construction of the body in western mechanics and is characterized as 'linear' behavior (Figures 7 & 8).

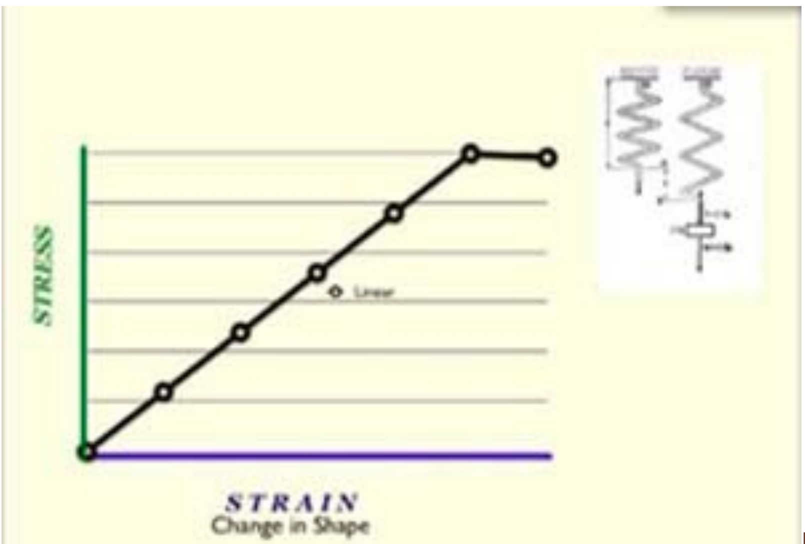

Figure 7. Linear Stress/ Strain curve

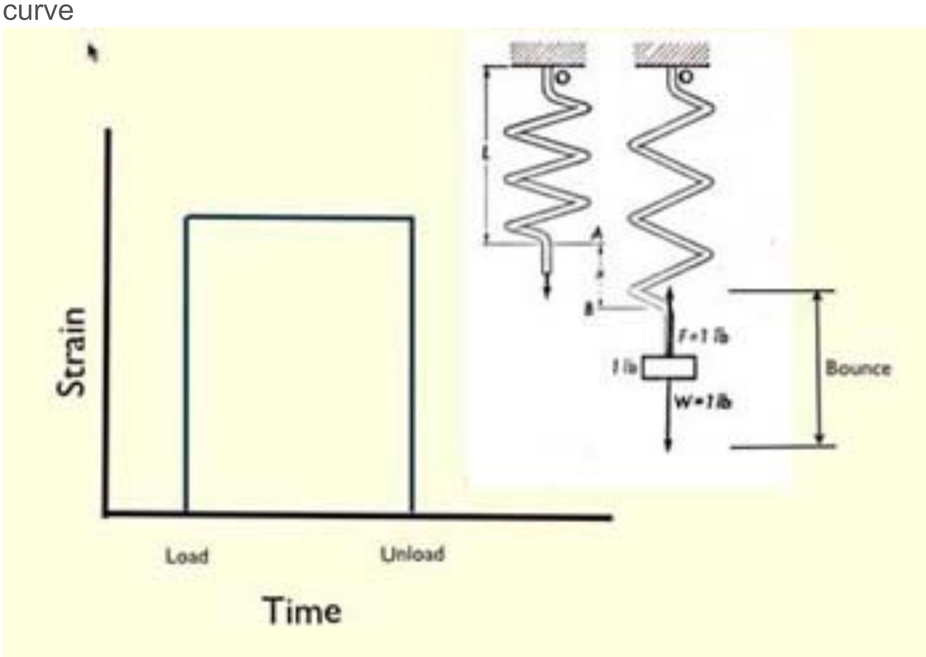

Figure 8. Behavior of a linear spring

The icosahedron, tensegrity spring is different and characterized as 'nonlinear'. In the resting state, there is always some residual tension or 'tone' in the system so it is never completely relaxed. If you add a kilo weight it may distort 15cms. But add another kilo and the distortion may only be 7cms, then 4cms, then 1cm. The icosahedron spring gets stiffer and stronger as you load it (Figure 9).

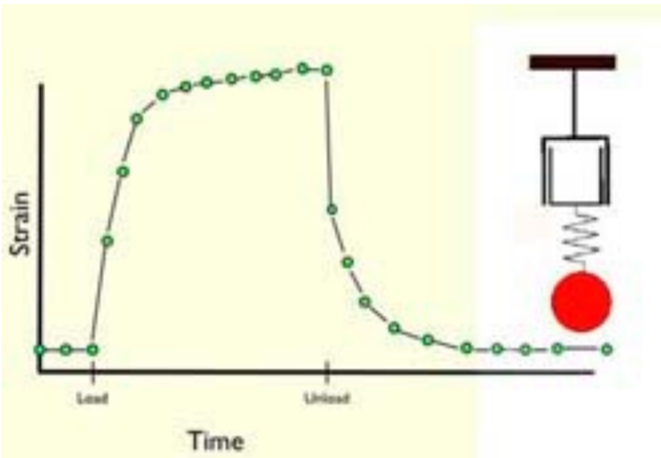

Figure 9. Non linear S/S curve. A spring and dashpot in series

You can see that as you add more weight a great amount of energy can be stored with very little change of shape of the icosahedron spring. When released, there is not the sudden, total release of stored energy as there is in a linear spring, but a great amount of energy can be released early and the last part can be released slowly and gently; a splashdown rather than a hard landing. This softens the blow and removes the bounce and jerkiness. As noted, not all the energy is released, some remains in storage (Figure 9). Grab onto your earlobe and pull. At first it distorts easily, but then it stiffens and pulling on it doesn't change the shape very much. Let go. It regains most of its original shape quickly, but the last bit is very slow. It does not bounce back like a rubber band and slap you on the side of the head. This is often termed in biomechanical circles as 'visco-elastic' as it has properties that in some ways are like fluid and in other ways, like a stiff elastic spring. In biologic bodies with bones, the stiffest icosahedrons are the bones and the most energy can be stored there. When compressed or expanded the movement of the icosahedron is helical, like the threads of a wood screw, and this is consistent with what we know of normal body movement. When it behaves as a stiffening fluid, it becomes a shock absorber, soaking up the energy rather than focusing it.

Those of you who are martial art practitioners already know you don't stand stiff and upright but move in all directions like a break-dancer. You know that the energy flows in and out from deep within the system and that you can bring energy up from the squishiness of your cells out to harden on the tips of your fingers. Your body is never completely flaccid; some tone always remains in the system. To get the maximum energy you screw yourself down and then explode with tremendous force from within, but never overshoot your mark. Pulling the force from deep within your structure is recruiting the entire body mass. Newton's second law of motion is force equals mass times acceleration (F = ma). (Imagine the difference if a small car moving at 5MPH strikes your automobile or a bus moving at 5MPH strikes your auto; quite a difference). Consistent with that law, striking a blow with your whole body creates a greater force than just striking with your fist, as you are increasing mass. In the standard post and lintel model, the arm and fist are just hanging off the body mass and operate independent of it. In a conventional boxers blow, speed (a) is all-important as the mass (m) is mostly the fist, in the biotensegrity model, the entire body mass is involved. When absorbing a blow, it reverses the process by soaking up the initial force, distributing it, and then gradually stiffing at the cellular level where the cells, rather than all the resistance landing on a local area. The bone breaking impact, rather than focused where the blow landed, will be he resisted by all your cells in a wave that spreads from the impact cite to a wall of billions of cells throughout the body, acting as perfect hydraulic shock absorbers, take up the blow. You go with the flow. Much of what seems unexplainable about the forces generated in martial arts are readily explained when the body is understood as a biotensegrity structure rather than as the common western post and lintel model.

The concept that the body is a tensegrity structure is not just a convenient model for martial arts practitioners. A turf toe injury in a quarterback will keep him from throwing a long pass. The quarterback throws from his foot, not just his arm. We know that biologic tissues characteristically behave as nonlinear and visco-elastic material. In fact, this nonlinear behavior has been felt to be an essential quality of living tissue. Different researchers in different parts of the world have demonstrated evidence that the entire fascial network is interconnected so that a continuous tension network is known to exist within the body. We also know that at least some of the joints, like the shoulder girdle, transmit their loads through the tension of the soft tissue and not the compression of the bones. There is mounting evidence that this is the way all joints work.

It is difficult to let go of concepts that have been part of us since childhood. The post and lintel –lever system has intuitively been our model of how the body mechanically functions. On the other hand, we really know better. Just watch any child first learning to throw a ball. Our first throws are done as if the arm is a separate structure, detached from the body. We soon learn that to throw a ball, you must put your whole body into it as the football quarterback does. We just never had a model to understand what we were doing. Biotensegrity gives us that model.