Physical Thoughts about Structure: The Elasticity of Fascia

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Abstract: Collagen is usually regarded as being inelastic. This results in a very misleading understanding of the role of fascia in the human structure.

Aristotle wrote that a heavy object (e.g., a big stone) falls faster than a light one (e.g., a leaf). This would seem so obvious—any child would agree. (It seems almost as obvious as geocentrism—the belief that the sun circles the earth once every day.) The obvious was so obvious that it took about 2000 years until there was a man crazy enough to doubt the obvious and question whether Aristotle had it right. He did this by asking Nature herself, in her languages of pure mathematics and dirty experiment. He is said to have thrown heavy and light stones from the Leaning Tower of Pisa and rolled stones down inclined ramps. He eventually found out that what seemed "obvious" was wrong. Without friction, small, light stones roll and fall as fast as big, heavy stones. He also supported the radical notion of heliocentrism – the fact that the earth circles the sun. By relegating questions about nature to the experimental method, deeming it the highest authority, Galileo established modern science and lost his freedom. Although this example could suggest that doubting the obvious can bring trouble, this article will nevertheless question a sacred cow in our world of structural bodywork: the supposed inelasticity of collagen.

When early generations of physiologists started to examine and classify various kinds of human connective tissue they found—among other stuff—some obviously elastic material, which they called elastin. But mainly they found an obviously tight material, which they called collagen (from the Greek kôlla, or glue; when cooked a long time, collagen becomes an amorphous glue). "Collagen is a tough, glue-like protein that represents 30% of body protein and shapes the structure of tendons, bones, and connective tissues." [1] This distinction between the "elastic" and "nonelastic" material has been deemed—and still may seem to be—obvious. It is my view that it is as misleading as a glue-related expression for collagen, even though it is still found in the majority of books about physiology and bodywork. For example, even though, I consider *Structural Bodywork* [2] to be one of the most precise books currently available on the subject of the elasticity of fascia, we find the usual confusion: collagen "has a tensile strength greater than steel; this means that its individual fibers are very inelastic. They...do not stretch" (p. 72).

To explain the "artificial" riddle of how elastic fascia can be made from inelastic collagen, rules of applied mechanics have to be contravened (denying the elastic fiber elongations in Figure 1). As a matter of fact, quite the opposite is true, with steel as well as with collagen: both exhibit wonderful elasticity. So it is a pity that even many of the most scientific papers in well-established physiology journals make a distinction between "elastic" fibers and "collagenous" fibers. It is possible that this confusion could cause harm, because a misunderstanding of how connective-tissue changes can lead to the wrong treatment. For example, "Certain heredity connective tissue diseases show hyper mobility of the joints and decreased elasticity of the skin. The lax skin is often mistakenly said by physicians to show increased elasticity, a confusion of terms which has probably been the basis of certain theories about the nature of the defect in these patients; the elasticity is decreased, not increased." [3]

So, what is elasticity and why is elastin usually, and inadequately, regarded as being "more elastic" than collagen? According to the majority of physicists, elasticity is not a quantity but a quality, so it cannot be either "more" or "less". Under stress, a more or less solid body has three ways of reacting (i.e., qualities): it can break or it can plastically deform (in either of these cases it remains in its new shape), or it can behave in an elastic way (returning to its original shape). There can also be a combination of these three. Deformations can be very small and almost invisible. Plasticity, as a result of inner friction and rupture, swallows the applied energy like a car bumper. In contrast, elasticity is a behavior that stores and returns the whole amount of energy. Elasticity allows deformation but restores the original shape when the load/stress is taken away, as seen in a bouncing soccer ball.

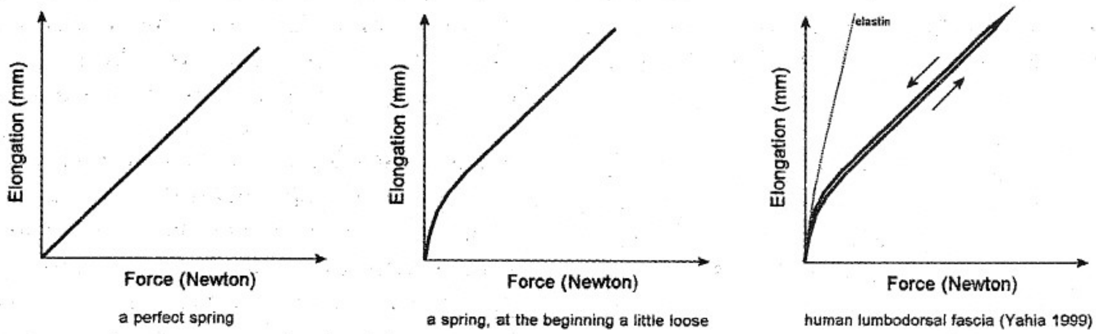

Figure 1. *At left, in a perfect spring an increase in applied force causes increased stretch. The curve demonstrates that double force produces double stretch (Hooke's law). The curve's steepness depends on stiffness: the stiffer the material, the less steep the curve.*

In the middle chart, we see that as pressure is exerted on the initially slack spring, it elongates a lot under a minimum of force.

At right is a sketch summarizing in principle many curves described by Yahia[18] (1999), with my addition for elastin, which is not included in Yahia's work. The similarity to the middle curve is clear. The loss due to viscosity makes the elongation of the fascia lag behind in stretching as well as in returning. The greater the circumscribed area, the greater the loss of energy.

If you were designing the body's fascia to move around in the earth's field of gravity, would you want it to fracture with each impact, to constantly yield without a return to its original shape? Of course not. It is probably okay if a little friction is produced—especially during a cold winter – but fascia should mostly behave in an elastic manner. That is why "God" or "evolution" invented collagen (more precisely, the collagen-glycosaminoglycan-complex), a material that is wonderfully elastic under tensile stress.[4,5]

Fascia is often described as being "viscoelastic", meaning that there is some viscous liquid inside, producing resistance and friction. Viscoelasticity is a form of "plastoelasticity", meaning a mixture of plasticity and elasticity. The energy going into viscous friction produces heat and the force is dissipated—the stretched fascia will not return on its own to the point where the stretching started. Muscles have to do the rest of the work. For example, under normal physiological conditions, an Achilles tendon returns approximately 93% of the applied stress energy and loses only 7% to mostly viscose friction.[6]

The big difference between collagen and elastin is stiffness. Stiffness is the value of how little an elastic material stretches under a certain load. It is a quantity that can be counted and compared and is equal to the slope of the stress-strain curve. Collagen is much stiffer than elastin. A collagenous tendon usually stretches at maximum to about 110% of its original length before it breaks, whereas elastin can elongate approximately 230%.[7] We could say that under the same load, collagen loses much less of its form than elastin does. Or, to put it another way, collagen can take much more loading before stretching as much as elastin. Or, even more simply, elastin is softer than collagen. Under conditions of physiological usage, both stretch to very different elongations but take and return the same amount of energy (almost all of it).

The tensile strength of a material should not be mixed up with elasticity or stiffness. It is another quantity: the maximum amount of tensile stress that a material can be subjected to before fracture.

The low value for stiffness makes the elastic behavior of elastin much more obvious. With collagen, the high value for stiffness has important advantages. First, it protects the body's shape. The way it does this is like climbing ropes made of woven nylon, which are required by law to be quite stiff. (A jumping or running human structure should hold its contents as firmly as the packaging of a sensitive electronic device delivered by mail order.) As a falling body you might think you'd prefer the smooth landing provided by a nice, soft, long-stretching bungee cord, but it is more likely that your body would reach the ground and smash before the bungee cord stopped its fall. (For bungee jumping to be fun, a long, free space to fall must be guaranteed.) Secondly, the high level of stiffness of collagen protects muscles from exhaustion: if they had to move bony levers through soft, long-stretching elastin tendons, they would have to move much further and do much more work. Thirdly, the stiffness of collagen makes movement faster, which protected us from becoming prey (moving bones via soft elastin tendons would make us very slow).[8]

Tensile stiffness is called "Young's modulus" and measured in gigapascals (GPa). Human tendons have a tensile stiffness a little less than solid nylon. The Young's modulus of a human tendon is 1.5 gigapascals,[9] while that of nylon is 3-7 GPa.[10] If we compare collagen with steel (ca. 200 GPa), we should compare elastin with rubber (0.01–0.1 GPa).

Which is more elastic, steel or rubber? It might seem obvious that steel is not elastic because there is not much visible elasticity. But somebody like crazy Galileo, might experiment by throwing a steel ball and a rubber ball onto the ground and measuring the height to which they rebound. (If you try this yourself, the "ground" must be strong and elastic enough that it is not destroyed or plastically deformed by the steel ball. The best surface would be a steel plate.) Usually the steel ball will rebound to a greater height than the rubber ball. This is because elasticity is not about losing shape in an impressive manner but about returning energy. The greater deformation of the rubber ball as it hits the ground produces more internal friction and more energy is lost.

As far as I know, the friction in pure elastin structures has never been measured. It is very likely that it is higher than in pure collagen structures because the longer stretching of elastin requires more movement of the viscose liquid, thus producing more friction. Seeing it this way, elastin is much "less elastic" than collagen.

Why do fascia and tendons need to be elastic at all? First of all, together with bones they form shock absorbers to prevent or minimize injury. A fall directly onto your skull would give you the feeling of what happens without these shock absorbers. By contrast, landing on your feet puts many effective shock-absorbing devices (made out of collagenous fascia, tendons, ligaments, interosseous membranes, and retinaculi) between your skull and the ground. The same structures act like springs, making the movement of a running human body resemble an elastic ball bouncing up and down easily. This way, muscles don't need to lift the weight of the body with each step.[11] Other than running, it is not clear yet how elastic fascia facilitates human gait. The Fascia Research Project at the University of Ulm, including the Rolfers, Dr. Robert Schleip and myself, is currently planning a research project on the function of human lumbodorsal fascia in walking (demonstrated by an animated video at www.fasciaresearch.de/swingwalker). If you do the right movement work, you might become an expert in ballistic walking.[12] With adequate gait style, the Achilles spring is stretching *before* and recoiling *during* each toe-off phase by about 7 mm.[13] With such a gait pattern, some African women are able to carry the equivalent of 20% of their body weight without any muscular effort.[14]

What is elastin for? Its low stiffness value is needed for structures that have to be able to change shape a lot, like the wall of the aorta (which has to stretch to accommodate the volume of blood from each heartbeat), the pulmonary alveoli (which have to provide the whole increased volume required with each inhalation), and the ligamentum nuchae (especially in quadrupeds that eat grass from the ground but at other times walk tall with a head of heavy antlers).

So why is elastin often found in collagen-dominant tissue? What can a rubber rope do alongside a steel rope? (i.e., Does it ever have the opportunity to work?) This is not clear yet. To me, the most convincing speculation is that elastin is kind of "the memory of the tissue" in cases of damage. If the collagen fibers are torn apart (while absorbing damaging energy like a car bumper), there is still the elastin, which has only elongated, to try to put everything back to where it belongs. It is important to note, however, that elastin lacks the strong resistance of collagen. If, for example, somebody has had a whiplash or a sprained ankle, he/she should move or be moved carefully and loading of the tissue avoided until the elastin has pulled the tissue back to where it came from and the collagen is repaired right at the fresh tears. Enduring load prevents the elastin from pulling everything back (this can happen easily), then the new collagen bridges over long gaps and grows into a hyper mobile and distorted structure.

What is still a big mystery for me is the purpose of the ligamenta flava. I cannot believe what I usually read. How can this soft sheet help to extend or stabilize the vertebral column when it is so close to the vertebrae's movement axis[15,16] and completely surrounded by many massive stiff collagenous ligaments more distant from the movement axis? What is there that would change much in its length or volume? Maybe the purpose of the ligamenta flava is rather to provide a tube for the spinal cord, like the aorta does for the blood stream? If you, dear reader, can find error in my thinking or offer any information, please be so kind as to contact me.

Now we can reasonably assume that Aristotle knew more about the elasticity of tendons than the glue makers did. After all, he taught Alexander the Great the natural sciences, and one factor behind Alexander's success was his pioneering large-scale use of torsion catapults[17] that used animal sinews (collagen). After the crucial siege of Tyre, he even gratefully canonized one of them. These devices were later called *ballista* from the old Greek word *ballô*—"to throw." Galileo built his own telescope (one of the first) and observed the movement of planets and moons. It is a pity that he did not invented a microscope instead — he could have observed the movement of human limbs, coined the expression *"ballistin"* instead of *collagen*, and saved us some confusion.

Endnotes

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Acknowledgements:

Hodeck, K. Personal communication 2007. (He is not the least of my sources, although I wished him many times to hell: he did not allow me one single, nice, quick, non-precise argument and is therefore guilty of this little article's length being threefold what I originally intended.)