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IMPORTANCE OF VISCOELASTICITY IN THE FOOT AND LOWER EXTREMITY

All structural tissues of the human body, including bone, cartilage, tendon, ligament, fascia, muscle, adipose and skin, will deform when subjected to loading forces. For example, when a tendon is subjected to a tension force it will elongate, and when a bone is loaded by a compression force, it will tend to shorten a small amount. The amount that the tissue is deformed, either in elongation due to a tension force or in shortening due to a compression force is known as *strain*. Strain is calculated as the change in tissue length divided by its original length and is expressed as a decimal fraction or percentage, with the formula being: *strain = change in length/original length* (Nigg, Benno M. and Walter Herzog (eds.): Biomechanics of the Musculoskeletal System, 2nd Edition. John Wiley and Sons, New York, 1999, p. 332).

All of the body's structural tissues, when placed under a loading force that then causes that tissue to deform a certain amount, or undergo a strain, will then tend to return back to its original length and shape once that loading force is removed from the tissue. Therefore, when bone, cartilage, tendon, ligament, fascia, muscle, adipose or skin is subjected to either a tension force, a compression force, or even a bending force and either lengthen, shorten or bend, these tissues will all tend to return back to their original shape. This type of deformation is called *elastic deformation* (Whiting WC, Zernicke RF: *Biomechanics of Musculoskeletal Injury*, *2nd ed*. Human Kinetics, Champaign, IL, 2008, p. 71).

This characteristic of the body's structural tissues being able to deform and then rapidly return back to their original shape (i.e., elastic deformation) are very important for both humans, and other animal species, during their lifetimes. For example, if a person walks 10,000 steps per day, that means that their Achilles tendon and plantar fascia are also stretched and returned to their original length 10,000 times per day and their metatarsals are bent and returned to their original shape 10,000 times per day also. This ability of our bone, cartilage, tendon, ligament, fascia, muscle, adipose and skin to undergo thousands of loading-unloading cycles elastically, all without any permanent change in shape or tissue damage, is the key to the individual being able to perform all their required weightbearing activities every day of their lives, and all without tissue injury.

However, if the magnitude of tension, compression or bending force on any bodily tissue is too high, there is an increased risk that the tissue will suffer what we call, in clinical terms, a *tissue injury*. Examples of tissue injury may include a partial or complete tear of a ligament, tendon, fascia or cartilage, or a stress fracture of a bone. These tissue injuries, which occur due to the tissue being subjected by too high of a magnitude of loading force and not returning to their original shape, original length, or original internal structure, are examples of *plastic deformation* (Whiting WC, Zernicke RF, p. 71).

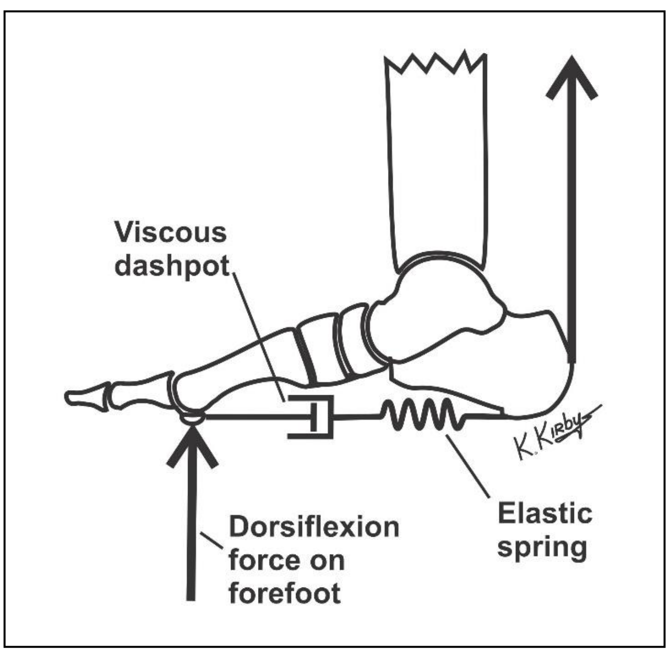

Figure 1. Using the Maxwell model of viscoelasticity, the time-dependent load-deformation characteristics of the plantar fascia may be effectively modeled.

One of the most interesting aspects of these *load-deformation characteristics* of the structural tissues of our bodies is that these tissues all exhibit *time-dependent behaviors*. For example, when a tissue is subjected to a loading force, the amount of deformation of these tissues will not only be dependent on the magnitude of force being applied, but will also be dependent on the duration of time which that loading force is applied. In addition, the internal force, or *stress*, that develops within that tissue, will be dependent on how rapidly that loading force is applied. For example, a rapid increase in loading force on the Achilles tendon will greatly increase the internal stress within the Achilles tendon fibers when compared to that same loading force being more gradually applied to the tendon.

The time-dependent characteristic of all body's structural tissues is due to these tissues having a fluid component within them, or having *viscous* characteristics. The rate of flow of fluid within the tissues creates extra resistance to deformation when the tissue is deformed rapidly, similar to how liquids may not flow as fast through a restricted passageway as through a larger passageway. The rate at which these tissues are deformed by a loading force is known as *strain rate* and the stiffening of tissues and increase in tissue stress at higher loading rates is known as being *strain-rate dependent* (Whiting, Zernicke, p. 90).

The combination of the elastic characteristics and viscous characteristics the body's structural tissues means that all of these tissues can be considered to be *viscoelastic*. In other words, bone, cartilage, tendon, ligament, fascia, muscle, adipose and skin all possess elastic characteristics of being able to return back to their original shapes once deformed by physiologic loading forces and also all have viscous characteristics of having time-dependent load-deformation behavior which are due to their fluid content. In essence, this *viscoelasticity* of the body's structural tissues is very important for the podiatrist to understand since it not only explains many of the biomechanical characteristics of the foot and lower extremity, but also explains how many foot and lower extremity injuries may occur and how the podiatrist may best be able to conservatively and/or surgically treat foot and lower extremity injuries in their patients.

Two of the important viscoelastic characteristics, or time-dependent load-deformation characteristics, of the body's tissues is *creep response* and *stress-relaxation response*. *Creep response* occurs when a constant loading force is applied to a tissue and the tissue initially rapidly deforms, then deforms more slowly, or creeps, as the loading force continues to be applied. The second time-dependent viscoelastic phenomenon seen within our structural tissues is *stress-relaxation response* and occurs when a tissue is subjected to a constant deformation, rather than to a constant force. In stress-relaxation, the initial deformation of the tissue will cause a relatively high stress within the tissue which will then result, over time, to a gradual reduction in stress within that tissue, or stress relaxation (Whiting, Zernicke, p. 91).

The first mechanical model of viscoelasticity was created by Scottish physicist James Clerk Maxwell, in 1867, and is known as *the Maxwell model of viscoelasticity*. Maxwell modeled the elastic component as a spring and modeled the viscous component as a fluid-filled dashpot, with the spring and the dashpot being placed in series across the applied loading force (Fig. 1). This relatively simple model demonstrates that when a tension force is applied to the spring on one side and to the piston of the dashpot on the other side, the combination of the spring and fluid-filled dashpot helps explain many of the time-dependent load-deformation characteristics of our viscoelastic tissues (Whiting, Zernicke 91, 96).

In my illustration (Fig. 1), the plantar fascia is represented by the Maxwell model where viscoelastic nature of the plantar fascia will first cause the spring to elongate and then over time as the load continues to be applied, the plantar fascia will elongate further due to the piston sliding within the dashpot. Not only does this model explain why the plantar fascia elongates more over time under constant load, but the model also predicts that when a plantar fascia load is applied more rapidly, the plantar fascia will exhibit increased stiffness. The possible mechanism of action of a plantar fasciitis night splint becomes readily apparent using this model. After the night splint is placed on the lower extremity, with the ankle at a 90^0 angle, the plantar fascia will initially have relatively large tension stress that will then lessen over the night while wearing the splint. The reduced plantar fascial tension stress when the patient arises from bed will result in a reduced chance of first-step pain in their plantar fascia upon arising. Understanding the viscoelastic behavior of the structural tissues of the foot and lower extremity allows the podiatrist to not only better appreciate foot and lower extremity biomechanics but also will allow the podiatrist to design better treatments for their patients.

Kevin

Kevin A. Kirby, D.P.M.
Biomechanics Director