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VISCOELASTICITY WITHIN THE TISSUES OF THE FOOT AND LOWER EXTREMITY

All the structural components of the human body (i.e., bone, cartilage, muscle, tendon, ligament, fascia, adipose and skin) possess the mechanical characteristic known as *viscoelasticity*. In other words, these tissues all possess both viscous and elastic load-deformation characteristics. The combination of both these load-deformation characteristics, viscosity and elasticity, which are inherent within our bodily tissues, will affect how these structures deform under load and how they will respond once loading forces are removed.

All the tissues of the foot and lower extremity will temporarily deform under load. Tension forces will tend to elongate the tissues, whereas compression forces will tend to shrink the tissues. For example, if an examiner dorsiflexes the foot during an ankle joint dorsiflexion test by placing manual force on the plantar forefoot, a tension load will be applied to the Achilles tendon which will cause the Achilles tendon to elongate slightly. Additionally, the compression loading force from the examiner's hand during the ankle dorsiflexion test will also compress the soft tissues of the plantar forefoot and temporarily reduce the thickness of these soft tissues. Once the examiner removes their hand and the manual loading force from the plantar forefoot, not only will the soft tissue compression force on the plantar forefoot be removed but also the tension loading force will be removed from the Achilles tendon. As a result, the soft tissue structures of the plantar foot will return back to their original thickness and the Achilles tendon will return back to its original resting length.

The ability of the tissues of the foot and lower extremity to first deform under load and then return back to their original shape is known as *elasticity* or *elastic deformation.* However, if the loading force is too great, the tissue may become permanently deformed and unable to return back to its original shape once the loading force is removed. This type of permanent deformation that may occur due to large magnitudes of loading force is known in biomechanics as *plastic deformation.* Many common injuries seen in podiatric practices, such as partial or complete tears of ligaments and tendons, tearing of fascia, and stress reactions, stress fractures and displaced and non-displaced fractures of bone, represent examples of plastic deformation within the structural components of the foot and lower extremity (Whiting WC, Zernicke RF: *Biomechanics of Musculoskeletal Injury*, *2nd ed*. Human Kinetics, Champaign, IL, 2008, p. 71).

All the structural components of the foot and lower extremity also exhibit load-deformation qualities which are *viscous*. One of the most common modelling techniques to illustrate the viscous nature of tissues is to use the mechanical analogy of a *dashpot.* A dashpot is made up of a piston inside a fluid-filled cylinder that is either pushed together with a compression force or pulled apart with a tension force, thereby moving the piston within the cylinder.

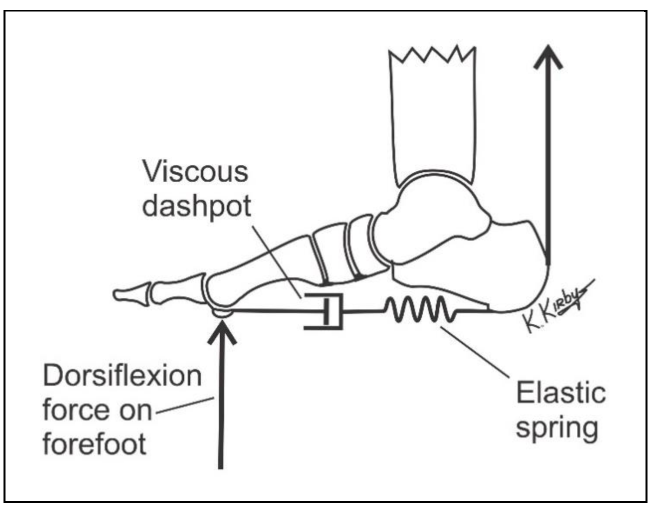

Figure 1. A constant dorsiflexion force acting on the plantar forefoot will dorsiflex the forefoot on the rearfoot, gradually elongating the plantar fascia. The Maxwell model of an elastic spring and viscous dashpot linked together in series provides a basic mechanical description of the time-dependent nature of the load-deformation characteristics of the plantar fascia.

Using a dashpot to represent the viscous nature of the structural tissues of the body is valuable since this mechanical analogue clearly illustrates the *time-dependent* load-deformation characteristics of our body's structural tissues (Fig. 1). For example, when a small amount of tension force is applied to the piston and cylinder to pull them apart, the piston will very slowly slide within the cylinder, slowly increasing its overall length over time. However, when a large amount of tension force is suddenly applied to the piston, the piston will resist moving quickly within the cylinder, even though the deforming force may be quite large. This viscous characteristic of a tissue, where a large loading force may not be able to suddenly deform a tissue, will greatly increase the internal stress on the structure under load, and, in this example, can greatly increase the tension force acting on the piston and cylinder. The end result is that the time-dependent viscous nature of the body's tissues will significantly affect how the tissues will deform under load, with the speed of the application of loading force being critical to how that tissue responds. The amount and rate of deformation of tissues is known as their *strain rate* and, as such, the tissues of the body are known as being *strain-rate dependent* (Whiting, Zernicke, p. 90).

A clinical example of strain rate dependence in human tissue would be when the plantar fascia is subjected to one of two types of tension force, either a slow, steady increase in tension force or a relatively rapid and sudden increase in tension force. For example, if the plantar fascia is subjected to a relatively small tension force that causes a 3 mm elongation of the fascia over a relatively longer period of time of 10 seconds, it would be subjected to a low strain rate of only 0.3 mm/sec. However, if the plantar fascia is subjected to a relatively large increase in tension force over a relatively short period of time, such as being stretched 3 mm in 10 msec, then it would be subjected to a high strain rate of 300 mm/sec. This 1,000 time increase in strain rate within the plantar fascia may lead to much larger chance of tearing within the fibers of the plantar fascia than if the plantar fascia was allowed to stretch over a longer period of time. This means that higher strain rates acting on or within the tissues of the body have a greater potential to cause tissue injury due to their viscoelastic nature which causes them to become stiffer when they are deformed more rapidly.

One of the models used in biomechanics to describe viscoelastic behavior is the Maxwell model, where the elastic nature of the material is modeled as a spring and the viscous nature of the material is modeled as a dashpot, with the spring and the dashpot connected together in series (Fig. 1). The Maxwell model, when applied to the plantar fascia, demonstrates that when a tension load is applied to the fascia, the plantar fascia will stretch elastically due to its spring-like nature, but will also elongate gradually over time due to its time-dependent viscous nature. This simple model demonstrates that as a load is applied, the body tissue will stretch more over time, and when the load is applied more rapidly, the tissue will become stiffer. The combination of these two mechanical properties, elasticity and viscosity, within the structural tissues of the body are why these tissues are considered to be "viscoelastic" in nature (Whiting, Zernicke 91, 96).

The two most important time-dependent viscoelastic mechanical characteristics of the body's tissues are known as *creep response* and *stress-relaxation response*. *Creep response,* or more simply *creep,* occurs when a tissue is subjected to a constant loading force and will gradually deform more over time. For example, a constant tension force on the Achilles tendon will gradually elongate the Achilles tendon a small amount over time while an Achilles tendon stretching exercise is being performed by an individual. *Stress-relaxation response* is another time-dependent viscoelastic phenomenon seen within the tissues of the body and occurs when the tissue is subjected to a constant deformation, rather than to a constant magnitude of force. As a tissue is deformed (i.e. stretched or compressed) a given amount, that tissue will show an initial rapid increase in resistive force in its first phase of loading. However, as the duration of constant tissue deformation is prolonged, the tissue will demonstrate a gradual decrease in resisting force during its second phase of loading which reduces or "relaxes" the stress within that tissue (Whiting, Zernicke, p. 91).

For example, when a patient wears a plantar fasciitis night splint, the plantar fascia is subjected to a relatively small increase in tension force due to the ankle being held at a 90° angle while in the splint. The plantar fascia will initially have a relatively large amount of tension stress within its fibers as it resists dorsiflexion of the forefoot on the rearfoot. However, if the splint is being worn over a longer period of time, the tension stress within the plantar fascia will decrease due to the time-dependent stress-relaxation response and viscoelastic mechanical characteristics of the plantar fascia. Understanding these load-deformation characteristics of the bodily tissues will allow the podiatrist to better appreciate the biomechanical nature of the foot and lower extremity and help improve the treatment decisions made by the treating podiatrist.

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