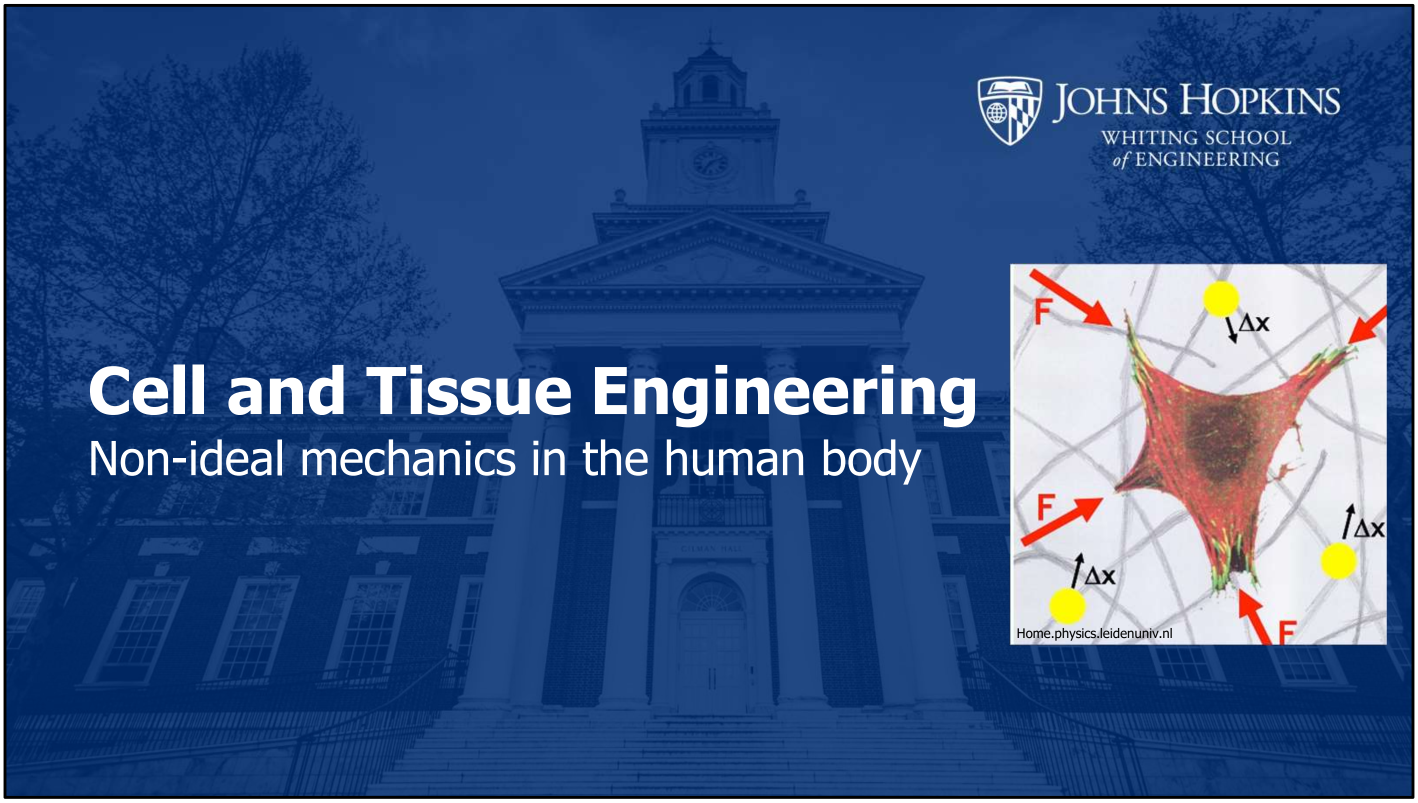
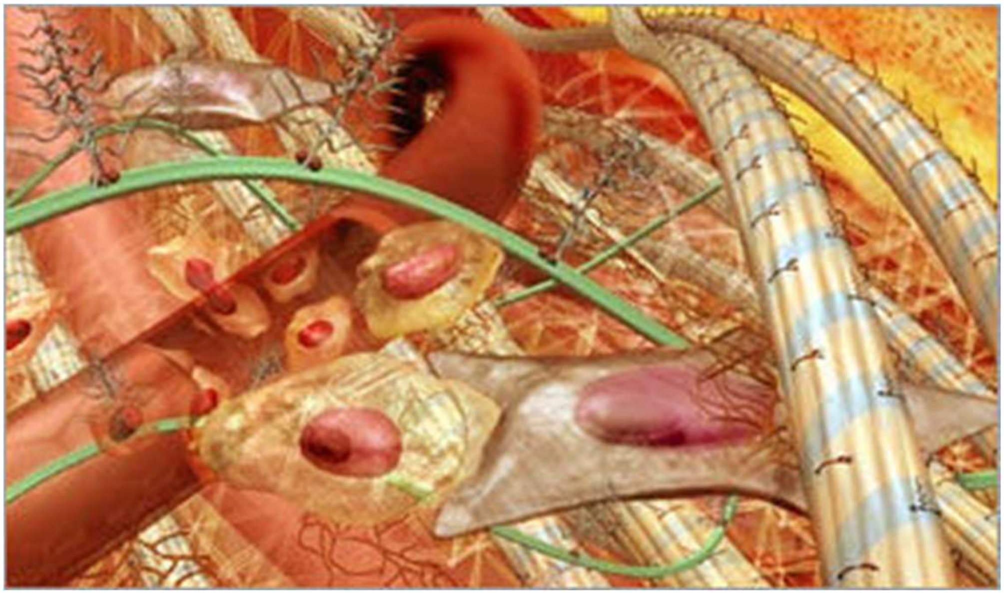



Welcome to Cell and Tissue Engineering. In this video, we will talk about more complex, non ideal mechanics in the human body.

We'll use the principles we've already learned to describe complex materials in the human body. Those that are not either solid or fluid but are BOTH solid and fluid. Think back to the earlier slide where we paused and took a deep breath to stretch our alveolar cells 20%. We took those sells from a solid-like phase / deformation to a fluid-like phase / deformation.

## Modeling non-ideal human tissues



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In the last lecture we talked about ideal systems – elastic solids and incompressible fluids.

We saw some fundamental equations to compute and analyze the these ideal materials responding to forces.

There are times when it will be valid to make the assumptions that human tissues behave in this way – but there are many times that we can't.

In this lecture we'll discuss was to model non-ideal human tissues. Materials that have both solid and fluid behaviors.

# Muscular hydrostats are both solid and fluid





Superstock.com; Wikipedia.org

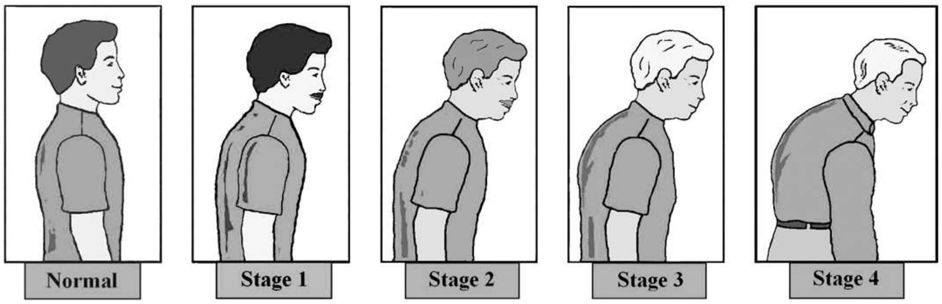
**Muscular hydrostats** are structures that consist of mainly **muscles** and have no **skeletal support.**

Muscles themselves are composed of mainly water – 80% in fact. **Hydrostats** work by **pushing around** this fluid, creating hydraulic movement.

These structures, and others including skin, clearly have fluid properties but also behave as elastic solids.

For example, they return to their original shape after deformation within their **elastic limit** and when loaded many of these materials **deform rapidly**

## Biological tissues: creep and stress relaxation behaviors





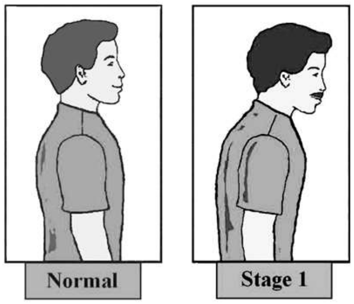


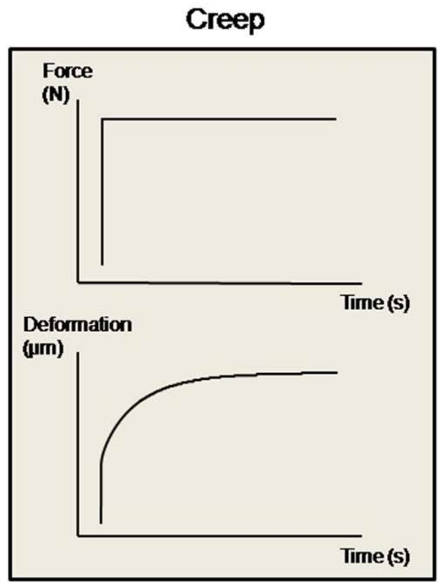



After loading and rapid deformation, biological materials often continue to deform slowly.

For example, if you sat at a desk for a long period of time you may notice your start to round your shoulders forward. You're uncomfortable, you're slumped.

## Biological tissues: creep and stress relaxation behaviors

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Pptaccess.com; Intechopin.com

Ligaments, which connect bones to bones, can rapidly deform with force (or body weight in this case), but when left left under a constant force, they will slowly **keep elongating and stretching**. This behavior is called **creep**.

And it can happen after as little as 20min sitting.

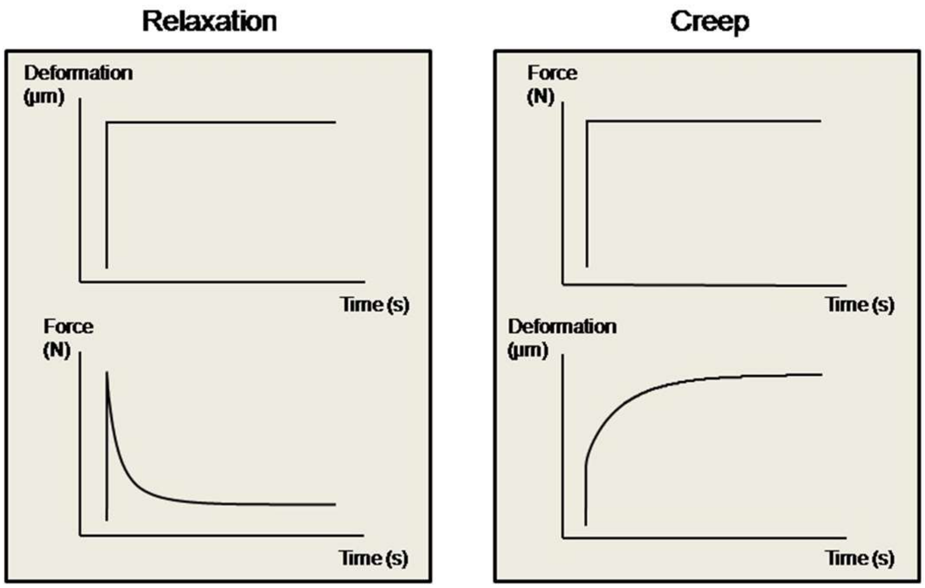
Here are what the force and deformation graphs look like – on the top you can see the application of a step force.

On the matched deformation curve below you see an initial rapid deformation, following by a period of slow deformation which eventually plateaus at the max elongation limit of the tissue.

This deformation you see in this creep curve can have many different shapes depending on the exact properties of the material.

Here you see a deformation that is **smooth**, others could, for example, have a **sharper break** between the elastic and fluid phases.

## Biological tissues: creep and stress relaxation behaviors



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Another behavior common in biological tissue is call **stress relaxation**.

This behavior is easiest to imagine when you think of athletes stretching before a workout.

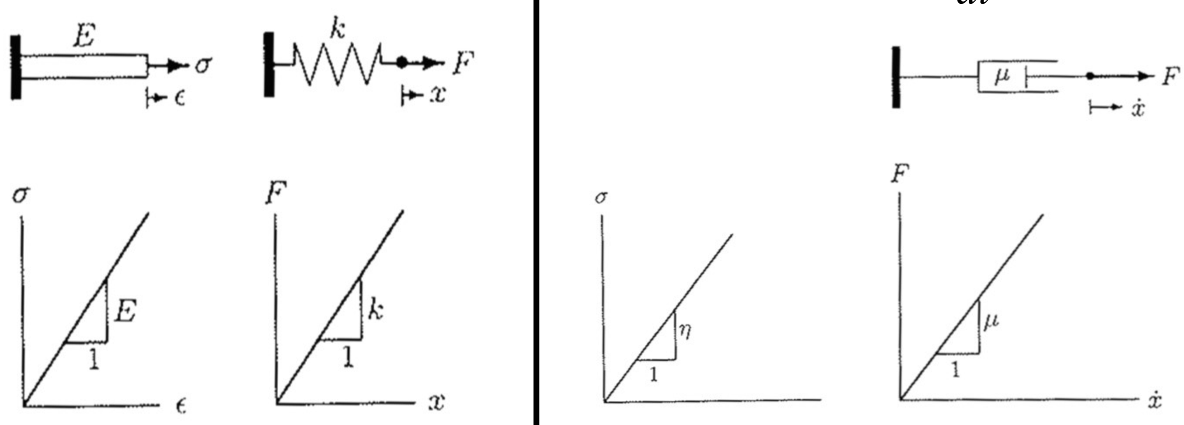
If your tissue (ligament in this case) is extended in a stretch for a long period of time (- so here we see the step deformation) , you'll see the that the stress in that tissue will dissipate. **This is the tissue relaxing so to speak.**

How do we model these non-elastic behaviors?

## Modeling viscoelastic materials with springs and dashpots

$$\sigma = E\varepsilon \qquad F = kx$$

$$\sigma = \eta\dot{\varepsilon} \qquad F = \eta \frac{dx}{dt}$$



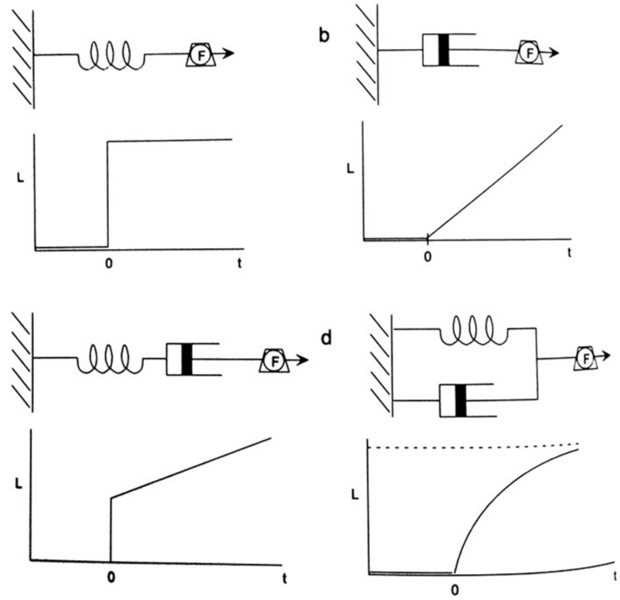



Earlier, we saw that we could model elastic solids at springs using Hooke’s law. This spring element gives us the rapid deformation.

To get the slow deformation characteristic of a fluid, we employ a **dashpot model.** A dashpot is simply a cylinder and piston. Friction between the two creates a slow. I give you the stress strain relationship here and the force deformation relationship here.

Combining the spring and dashpot, we can create a **viscoelastic model**.

## Modeling viscoelastic materials with springs and dashpots

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Saltzman, Tissue Engineering

Ok so here are our displacement curves for the **spring**, and here is the creeping **dashpot**.

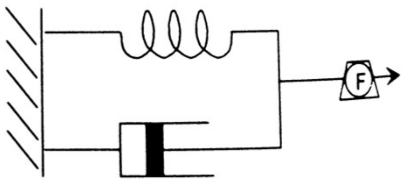
We can combine these two models in a variety of ways creating **different types of viscoelastic models**.

When in *series* we create what is called a **Maxwell model**. In this model there is an instantaneous spring deformation followed by the slow creep of the dashpot. <u>These elements are feeling the **same force.**</u>

When we combine the spring and dashpot in *parallel* we get a **Voight** model. In parallel, there is no instantaneous displacement, instead we get a **graded** creep that **plateaus** with the full extension of the spring. <u>Instead of feeling the same force, these elements will undergo the **same deformation** or strain.</u>

## Deriving differential equations for viscoelastic models

### Voight Model




$$F = kx \quad \textbf{spring}$$

$$F = \eta \frac{\delta x}{\delta t} \quad \textbf{dashpot}$$

$$F = F_1 + F_2$$

$$F = kx + \eta \frac{\delta x}{\delta t}$$



We can use the basic equations for the spring and dashpot to derive the governing equations for different viscoelastic arrangements.

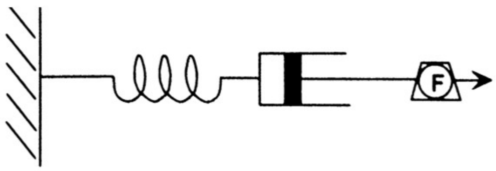
Let’s take the Voight model for example. Here we have the spring and dashpot in series.

As I just mentioned with the Voight model, the spring and dashpot will have the **same deformation and strain**, however they will experience different forces. I’ll call those F1 and F2.

Together these forces will sum to the total force applied to the system. To write the force displacement equation we simply need to sub in for the individual forces felt by the elements.

## Deriving differential equations for viscoelastic models

### Maxwell Model




$$F = kx \qquad \textbf{spring}$$

$$F = \eta \frac{\delta x}{\delta t} \qquad \textbf{dashpot}$$

$$x = x_1 + x_2 \qquad \frac{dx}{dt} = \frac{dx_1}{dt} + \frac{dx_2}{dt}$$

$$\frac{dx}{dt} = \frac{dF/dt}{k} + \frac{F}{\eta}$$

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For the Maxwell model we have the **same force** felt by the two elements, but different displacements.

I've written here that the total displacement of this Maxwell viscoelastic is equal to **the sum of the displacements of the two elements**.

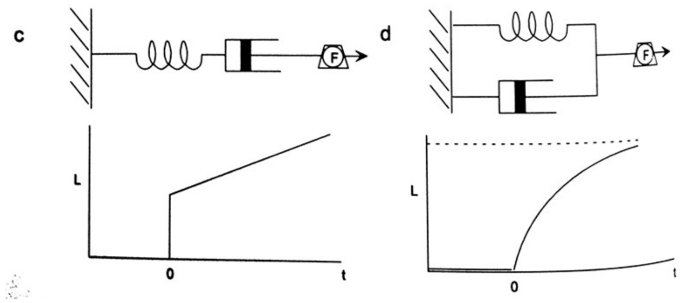
With this knowledge we can also say that the rate of displacement of the entire body is equal to the sums of the rates of change for the two elements.

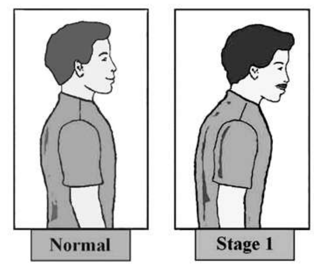
Now we take the time derivative of the spring equation and sub in for our rates of change.

In your homework you'll derive the ordinary differential equation for a **Kelvin model** – another common viscoelastic model for biological tissue.

# Review and rewind

**Viscoelastic modeling**






IN review this lecture discussed the mechanics and modeling of biological materials.

Specifically we discussed viscoelastics – the concept of modeling combination materials – that is materials which **both** exhibit solid and fluid behaviors including creep and strain relaxation.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