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Review article

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Mechanical state transitions in the regulation of tissue form and function

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Supplementary information

Supplementary Table 1: States of matter and definition of mechanical properties of materials.

State/ Property	Definition	Deformation	Biological examples
Solid	A state of matter with a defined shape. A solid material can resist a deformation force or it will deform a finite amount during a force application.	Reversible or irreversible	Most plant tissues, and some mature animal tissues such as bone or shell are solid.
Fluid	A state of matter without a defined shape, i.e. a fluid takes the shape of its container. A fluid cannot resist a deformation force, and continuously flows upon a force. Liquids and gases are fluids.	Irreversible	During development or wound repair, epithelial tissues can flow like a fluid to enable fast collective motion.
Elasticity	A property of solids. The ability to instantaneously deform under the application of a force and return to its original shape once the force is removed.	Reversible	Many extracellular matrix biopolymers such as collagen or elastin can exhibit fully elastic properties.
Viscosity	A property of fluids. It is a measure of resistance to flow under the application of force. A viscous material gradually flows and will not recover to the original shape.	Irreversible	The lipid bilayer of a cell membrane will exhibit mostly viscous properties.
Plasticity	A property of solids or fluids. The ability to deform irreversibly under the application of a force, leading to permanent changes in shape. Plastic deformation can occur in an elastic material when the stress applied to a material exceeds its yield strength, causing bonds in the material to move and rearrange irreversibly.	Irreversible	Stretching of an elastic network, such as an actin filament network, beyond a certain strain, can cause the network to break and remodel and show irreversible plastic deformation.
Visco-elasticity	Exhibits both viscous and elastic behaviour. When the elastic response of a viscoelastic material dominates its viscous response, it is said that the material is more ‘solid-like’. Conversely, when the viscous response dominates the elastic response, the material is more ‘fluid-like’.	Partially or fully reversible	Most biological materials, cells and tissues are viscoelastic. The cell cortex behaves like an elastic solid on short time scales but can deform like a viscous fluid over longer time scales.
Visco-plasticity	Exhibits both viscous and plastic behaviour. A viscoplastic material undergoes a time-dependent irreversible deformation when exposed to external stress. Viscoplastic materials are more ‘solid-like’ upon a small force, but flow in a ‘fluid-like’ manner upon a large force.	Irreversible	Stretching an elastic material, be it a biopolymer, cell cortex or tissue monolayer, beyond its elastic regime, will break contacts, induce remodelling and result in permanent plastic deformation.