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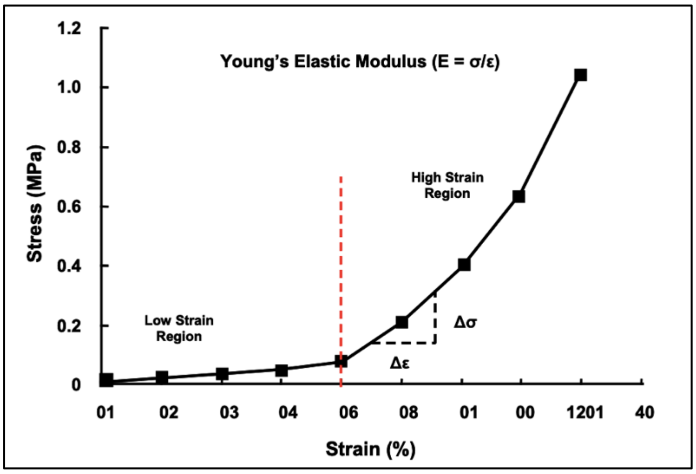
YOUNG'S MODULUS

What is it?	Young's modulus or Young's Elastic Modulus (E) is a measure of elasticity, in other words measure of the stiffness of an elastic material. It represents a relation between stress (σ, force per unit of surface area, F/A) and strain (ε, extension per unit length, dl/l) and thus is an intrinsic characteristic of the material. [Chida & Steptoe 2010] $$E = \frac{\sigma}{\varepsilon} = \frac{F/A}{dl/l}$$ In the blood vessels, the slope change of the stress-strain relationship, in other words the Young's modulus is related to the change in material properties due to the contribution of elastin and collagen to the arterial walls. The unit of elastic moduli can be given in newtons per square meter (N/m^2), whereas in engineering elastic moduli are often given in pascals [Medical Physiology 2022].
Why do we measure it?	Young's Modulus is a convenient property in order to understand the behaviour of the material when subjected to a force. It is one of the important indices to describe the mechanical properties of vessel walls such as arterial stiffness [Mackenzie 2002, Bank & Kaiser, 1998]. Also, pulse wave velocity (PWV – see 'pulse wave velocity'), which is the measurement of arterial stiffness, is a direct function of the arterial Young's modulus [Safar 2007]. By taking precise measurements and calculating the relevant curves, the Young's modulus of a variety of materials utilized in spinal surgery, as well as cortical and cancellous bones, may be calculated [Heary 2017]. Furthermore, several artery stiffness indicators have been suggested based upon the relationship between pressure and diameter of arterial distension. They, however, represent the total stiffness of the whole arterial wall while Young's modulus is able to show more subtle variations in the proportion of the constituents of arterial wall.
How can it be measured	Young's modulus can be obtained by compression or tensile test [Camasao & Mantovani 2021]. The test processes involve either slowly extending or applying compressive pressure until the material brakes. When it comes to blood vessels, in-vitro tensile testing has been used to study the viscoelastic nature of them. The procedure is mainly recording the load under tension at each strain increment, allowing the tissue to relax at each strain to determine the viscous and elastic component of the tissue. Viscous component measuring the energy dissipated during the relaxation, and the elastic component measuring the energy stored [Ebrahimi 2009].

	If it is assumed that arteries are circular and thin-walled, then Young's modulus can be computed from the area distensibility (DC) using: $$E = \frac{1}{DC}\frac{d}{h}$$ where d is the arterial diameter and h is the wall thickness.
Where is it measured?	Young's modulus usually measured for blood vessels, mainly to understand the mechanical properties and stiffness of the vessels. Arteries expand in size as transmural pressure is increased. Under physiological settings, an increase in pressure only moderately increases the radius, especially in muscle arteries, hence the artery's resistance (inversely proportional to r^4) does not decrease significantly. Veins act in quite different way. The pressure-volume diagram of a vein reveals that compliance, at least in the low-pressure region, is quite high - far higher than for elastic arteries [Chida & Steptoe 2010]. So, the resistance arteries are widely used for calculation of Young's modulus. There are also different Young's modulus constants for different tissues and organs. For example, the Young's modulus for native soft tissues and organs varies from 0.1 kPa to 1 MPa depending on the tissues' function and location [Liu 2015].
Figure	Figure from a publication:  Stress-strain curve of a typical artery. Elastin contributes to the mechanical properties of the lower region, while collagen plays a major role in the mechanical properties of the upper region. *Ebrahimi 2009. Mechanical properties of normal and diseased cerebrovascular system. Journal of vascular and interventional neurology.* https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3317338/. *Figure 2.*

References	Chida & Steptoe 2010. DOI: 10.1161/CIRCRESAHA.121.318061 Medical Physiology, Elastic Properties of Blood Vessels, 3rd Edition. Retrieved September 12, 2022 from https://doctorlib.info/physiology/medical/104.html Mackenzie 2002. DOI: 10.1093/qjmed/95.2.67 Bank & Kaiser 1998. DOI: 10.1161/01.HYP.32.2.356 Safar et al. 2007. DOI: 10.1111/j.1076-7460.2002.00695.x Heary et al. 2017. DOI: 10.21037/jss.2017.05.01 Camasao & Mantovani 2021. DOI: 10.1016/j.mtbio.2021.100106 Ebrahimi 2009. PMID: 22518247 Liu et al. 2015. DOI: 10.3390/ijms160715997

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[*] These definitions have been downloaded from https://vascagenet.eu/official-glossary and were released on 1st April, 2023.