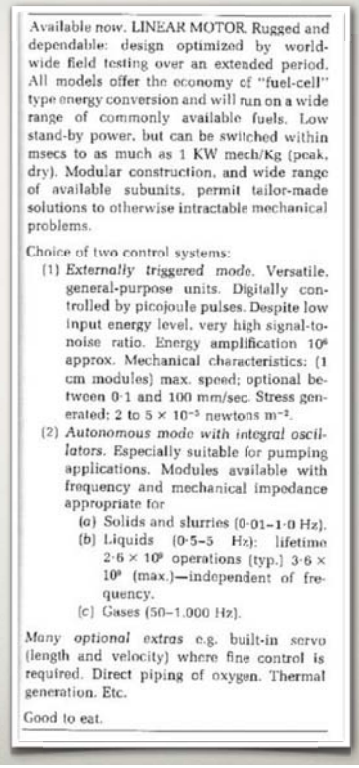
Muscle biophysics

Notice of a lecture presented by Professor D.R. Wilkie to the Institution of Electrical Enginers in London.



Available now. LINEAR MOTOR. Rugged and dependable: design optimized by world-wide field testing over an extended period. All models offer the economy of "fuel-cell" type energy conversion and will run on a wide range of commonly available fuels. Low stand-by power, but can be switched within msecs to as much as 1 KW mech/Kg (peak, dry). Modular construction, and wide range of available subunits, permit tailor-made solutions to otherwise intractable mechanical problems.

Choice of two control systems:

(1) *Externally triggered mode.* Versatile, general-purpose units. Digitally controlled by picojoule pulses. Despite low input energy level, very high signal-to-noise ratio. Energy amplification 10^6 approx. Mechanical characteristics: (1 cm modules) max. speed; optional between 0·1 and 100 mm/sec. Stress generated: 2 to 5×10^{-5} newtons m^{-2}.

(2) *Autonomous mode with integral oscillators.* Especially suitable for pumping applications. Modules available with frequency and mechanical impedance appropriate for

(a) Solids and slurries (0·01–1·0 Hz).

(b) Liquids (0·5–5 Hz): lifetime $2·6 \times 10^9$ operations (typ.) $3·6 \times 10^9$ (max.)—independent of frequency.

(c) Gases (50–1,000 Hz).

Many optional extras e.g. built-in servo (length and velocity) where fine control is required. Direct piping of oxygen. Thermal generation. Etc.

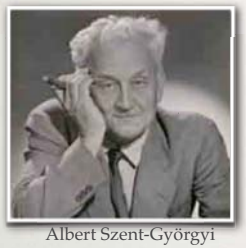
Good to eat.

Muscle

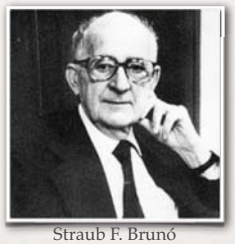
Tissue and/or cell specialized for the generation of force and movement.

It can only pull, not push (...).

Hungarians in muscle research



Albert Szent-Györgyi



Straub F. Brunó

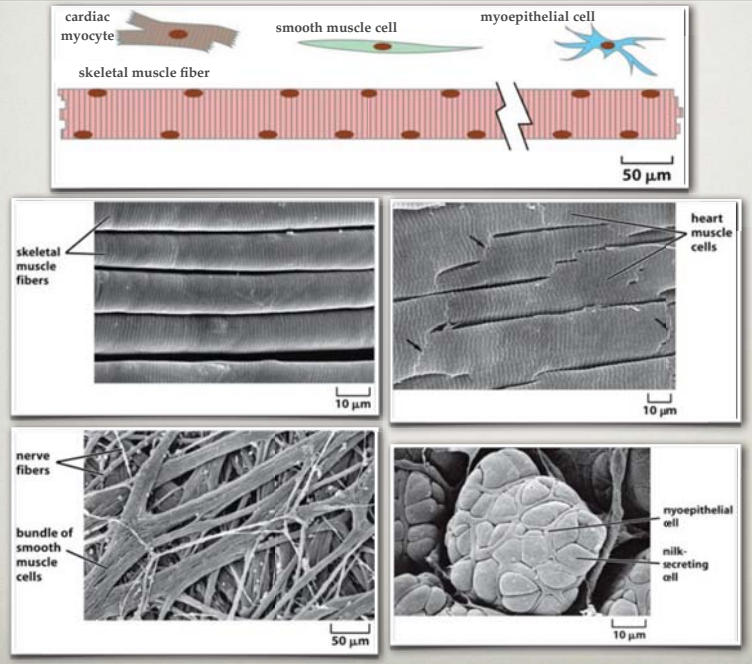
András Szent-Györgyi

János Gergely

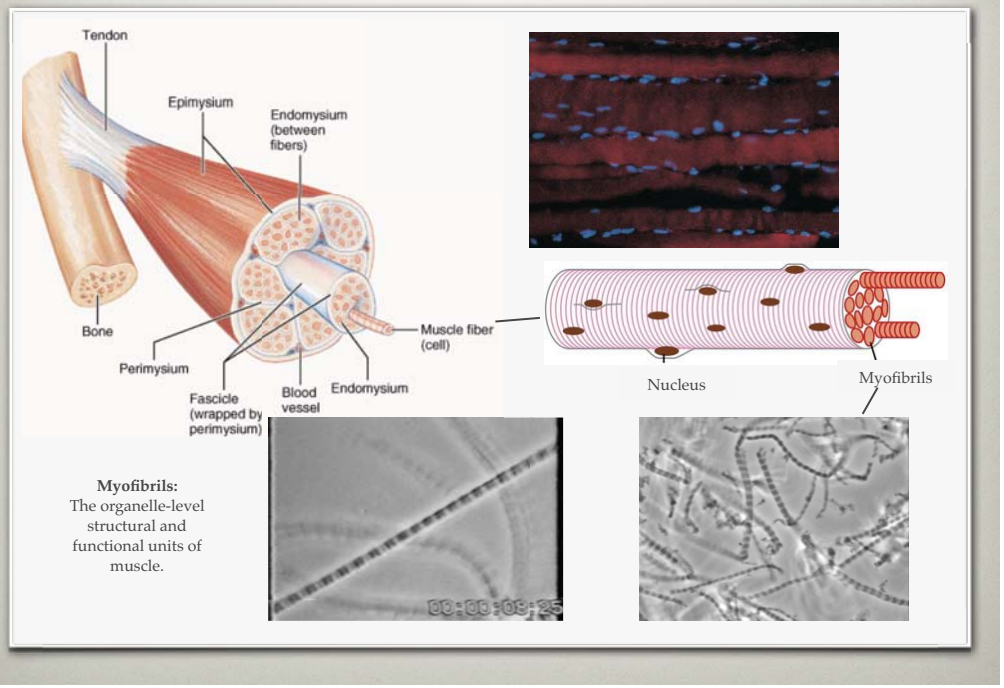
Katalin and Mihály Bárány

Ferenc Guba (fibrillin)

Types of muscle

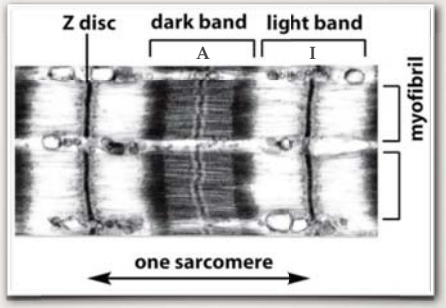


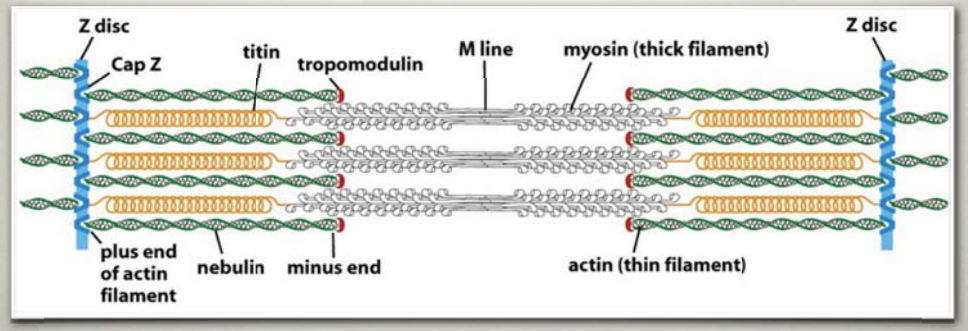
Skeletal muscle



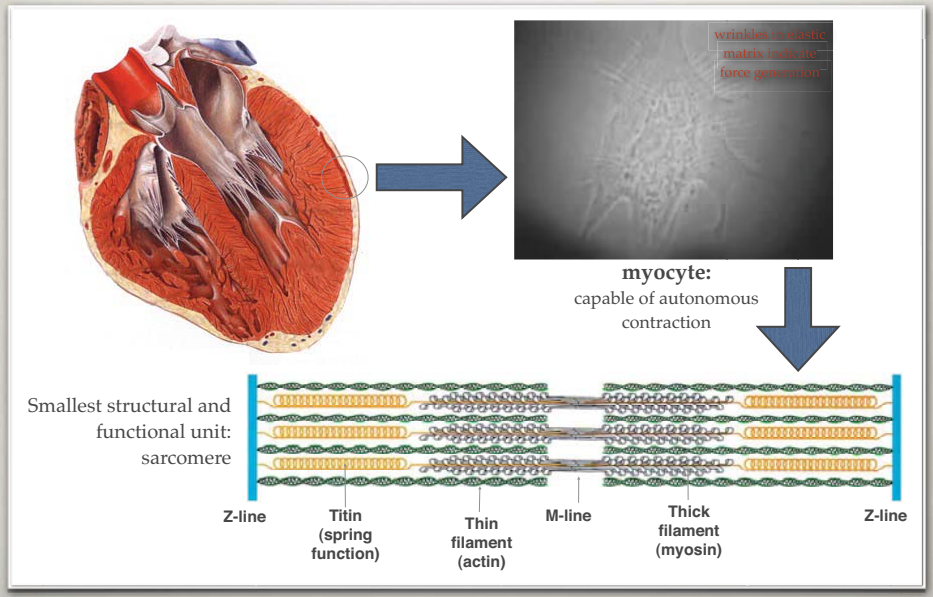
The sarcomere

sarcos: meat (Gr)
mera: unit
the smallest structural and functional unit of striated muscle.

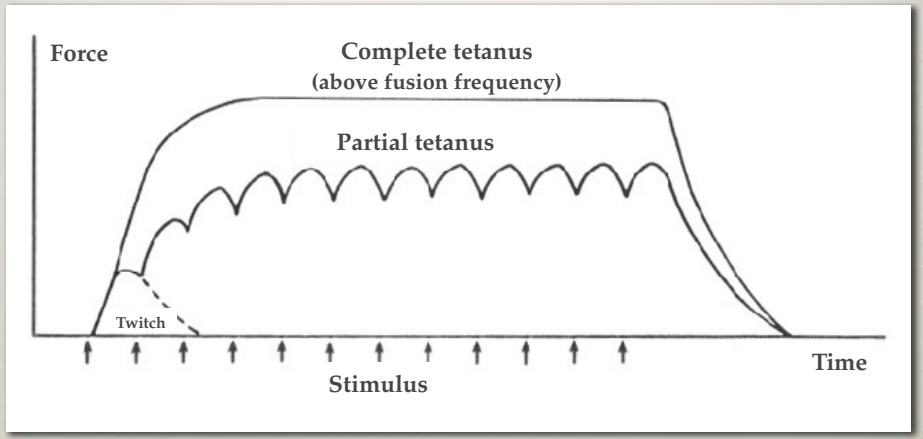




Heart muscle

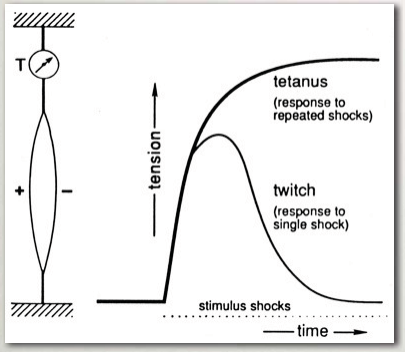


Basic phenomena of muscle function I.

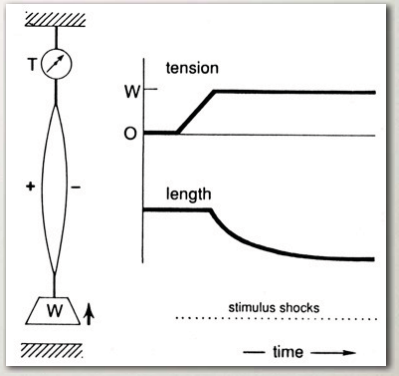


Basic phenomena of muscle function II.

1. Isometric contraction



2. Isotonic contraction



Auxotonic contraction (simultaneous shortening and force generation)

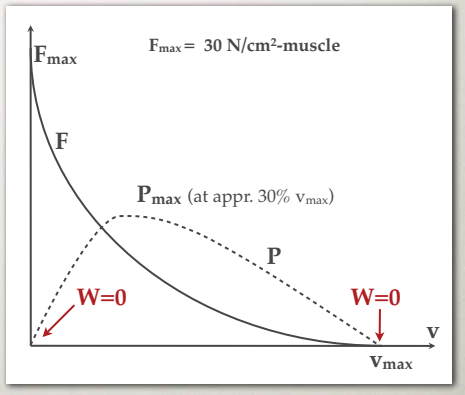
Basic phenomena of muscle function III.

1. Work, Power

$$W = Fs$$

$$P = Fs/t = Fv$$

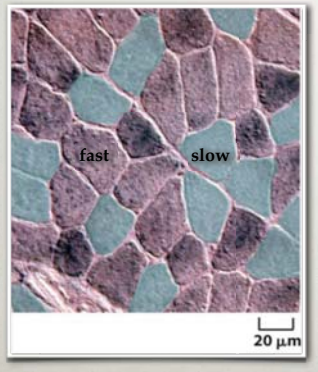
2. Force-velocity diagram



Energetics of muscle I.

Source of energy:

$$Mg.ATP^{2-} + H_2O \rightleftharpoons Mg.ADP^{1-} + Pi^{2-} + H^+$$



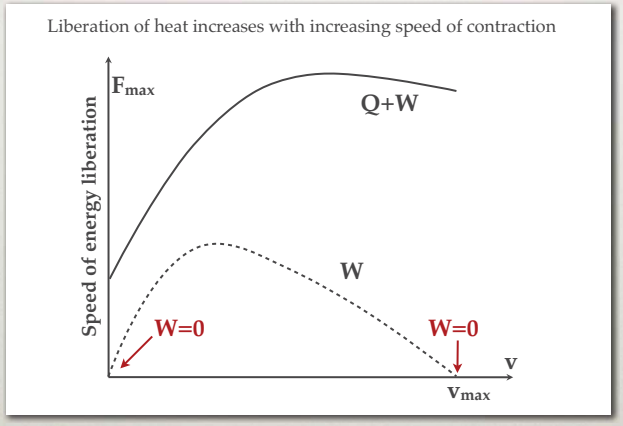
Type I fibers
- * rich in mitochondria
- * ATP generation by respiratory mechanisms
- * slow fatigue
- * rich in myoglobin: "red muscle"
- * innervated by thin, slow nerves
- * slow fiber
- * dominates in postural muscles

Type II fibers
- * few mitochondria
- * rich in glycogen
- * ATP generation by glycolysis
- * rapid fatigue due to lactate
- * devoid of myoglobin: "white muscle"
- * innervated by large, fast neurons
- * fast fiber
- * present in fast muscles

Energetics of muscle II.

Fenn effect

Liberation of heat increases with increasing speed of contraction

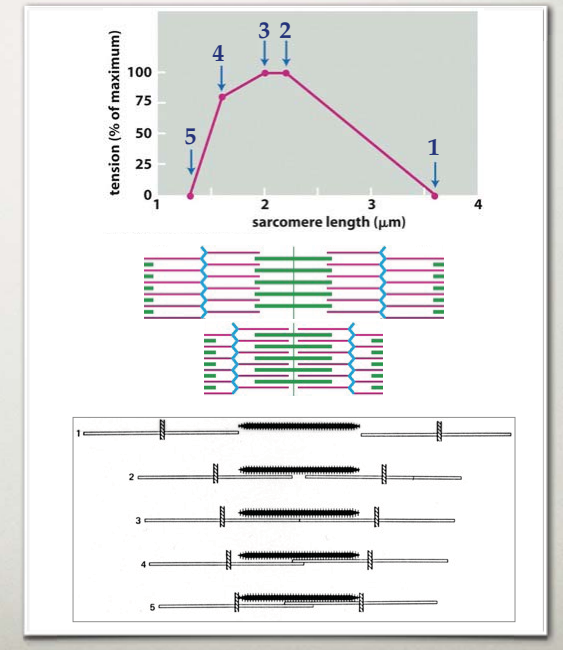


Mechanisms of muscle shortening

Phenomenological mechanism:

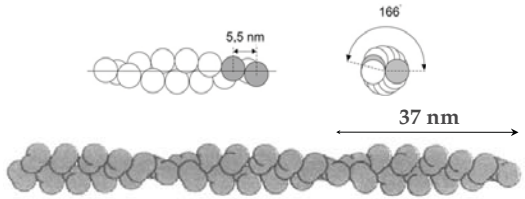
Sliding filament theory

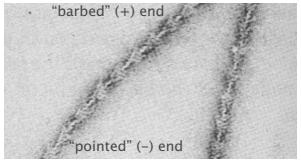
Andrew F. Huxley, Jean Hanson, Hugh E. Huxley



Molecular mechanisms of muscle contraction: Cyclic, ATP-dependent actin-myosin interaction

The actin filament





~7 nm thick, length *in vitro* exceeds 10 μm, *in vivo* 1-2 μm

Right-handed double helix.

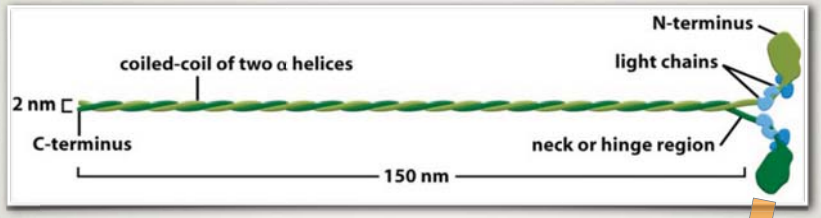
Semiflexible polymer chain (persistence length: ~10 μm)

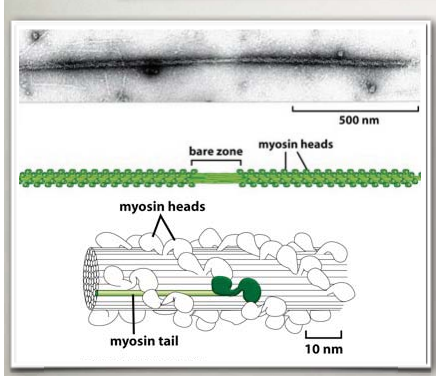
Structural polarity ("barbed", "pointed" ends)

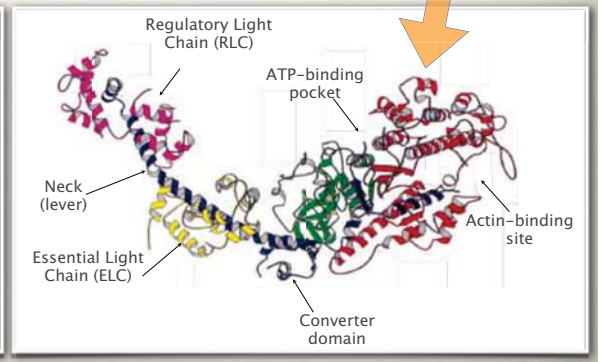
Tensile strength of actin: appr. 120 pN (N.B.: under isometric conditions up to 150 pN force may reach a filament.

Number of actin filaments in muscle: 2 x 10^{11}/cm^2-muscle cross section.

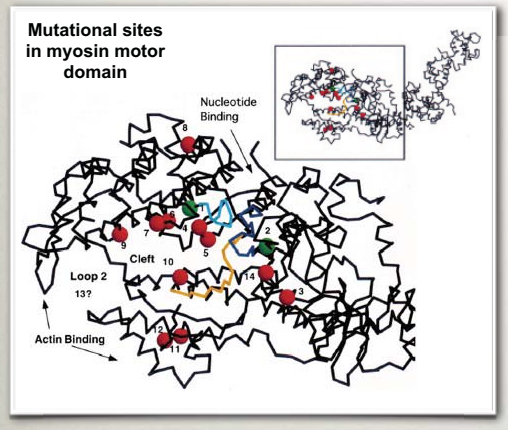
Myosin II





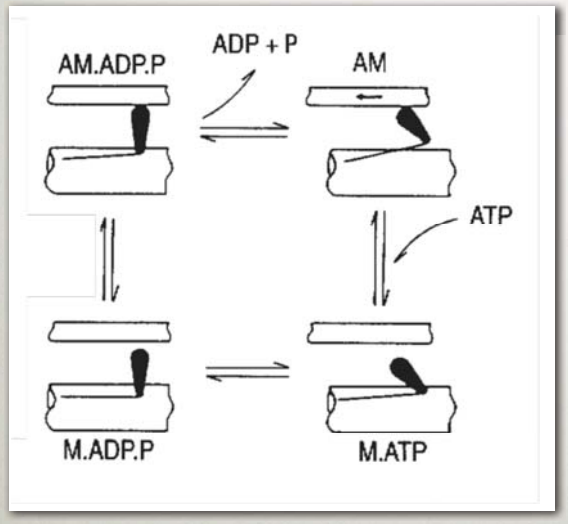


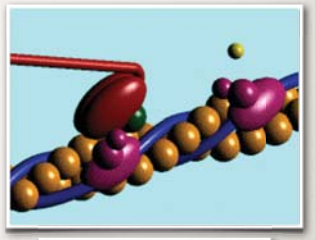
Myosin mutation – pathology

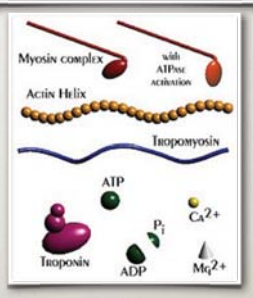


Arg403Gln mutation: hypertrophic cardiomyopathy

The myosin "cross-bridge" cycle

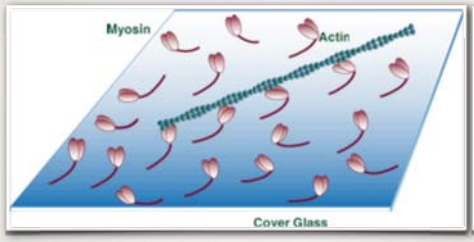






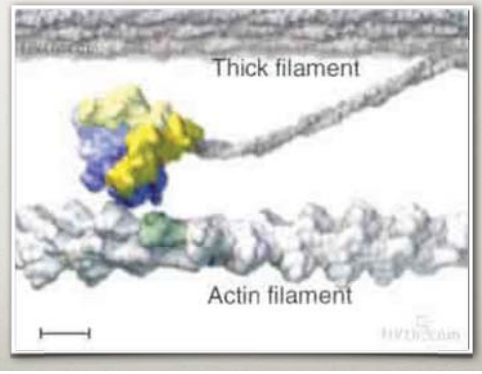
Models of muscle contraction

Experimental model: "in vitro motility assay"

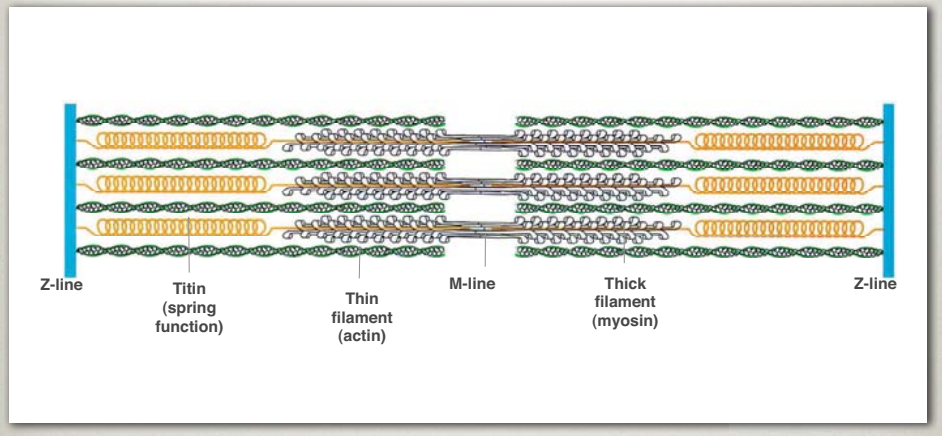


Structurel-functional model

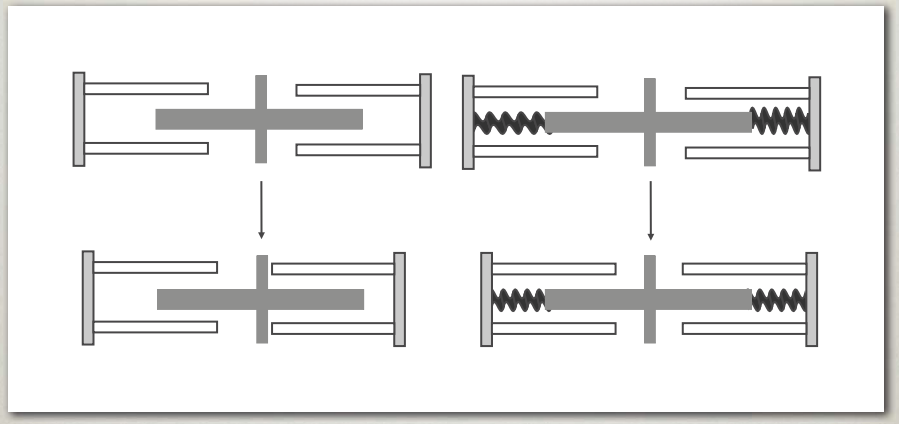
Step size: 5,5 nm
(distance between neighboring actin subunits)



Elasticity of striated muscle

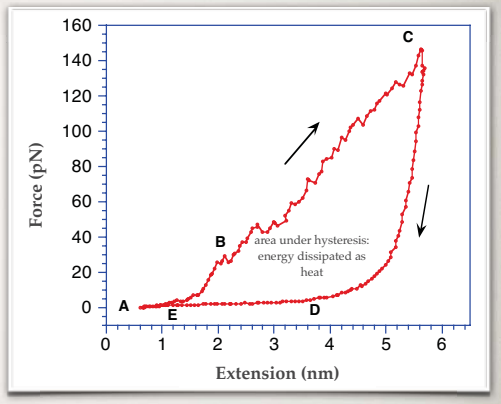


Role of titin in sarcomere: Limitation of A-band asymmetry

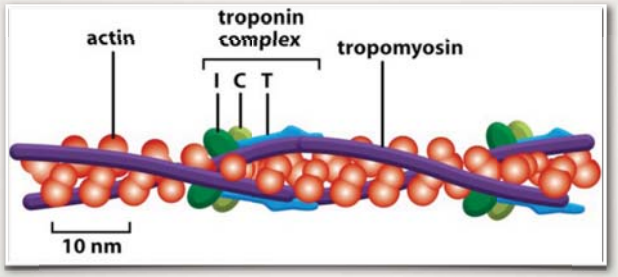


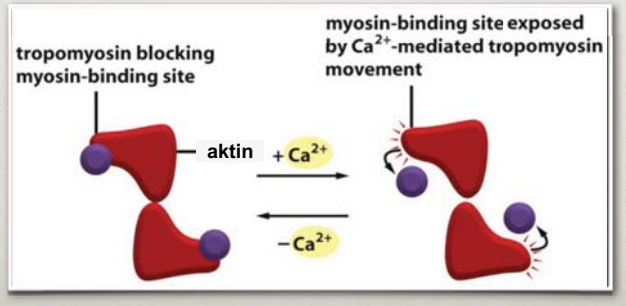
Mechanical properties of titin

Adjustable spring and shock-absorber



Contraction regulation in striated muscle





Excitation-contraction coupling