Mechanical Properties of Striated Skeletal Muscles

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PROBLEMS:

TYPES OF CONTRACTION: isometric, isotonic, auxotonic.

RECORDING OF MUCLE CONTRACTION: response to a single stimulus (twitch) - characteristic patterns.

ISOTONIC CONTRACTION

Physiological relationships:

- amount of shortening versus time and load,
- velocity of shortening as a function of load: *the velocity - force relationship* (the Hill law),
- muscle power as a function of force developed: *the power - force relationship*

ISOMETRIC CONTRACTION:

- summation of isometric contractions – tetanus
- active and passive force components;
- *the force - length relationship*

LEVER ACTION OF MUSCLES AND BONES

1. Basic terms:

Tension – the force exerted by a contracting muscle on an object

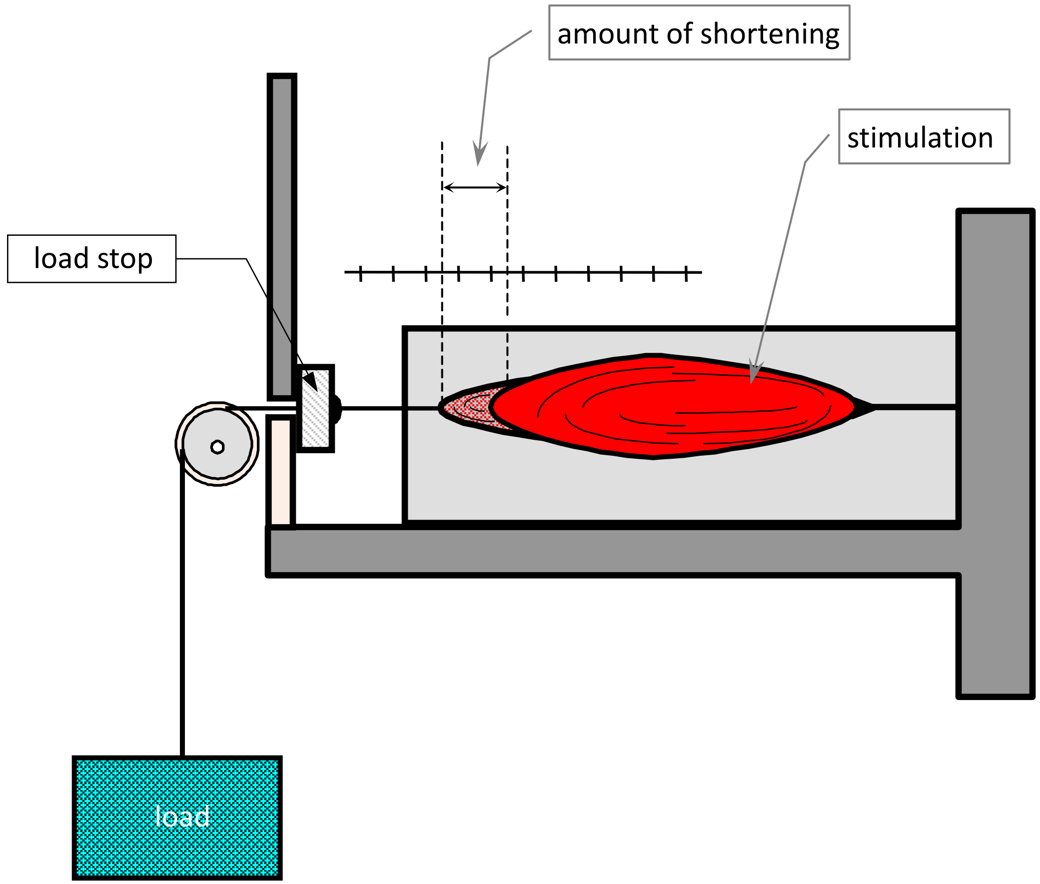
Load - the force exerted on the muscle by the object.

2. Types of contraction:

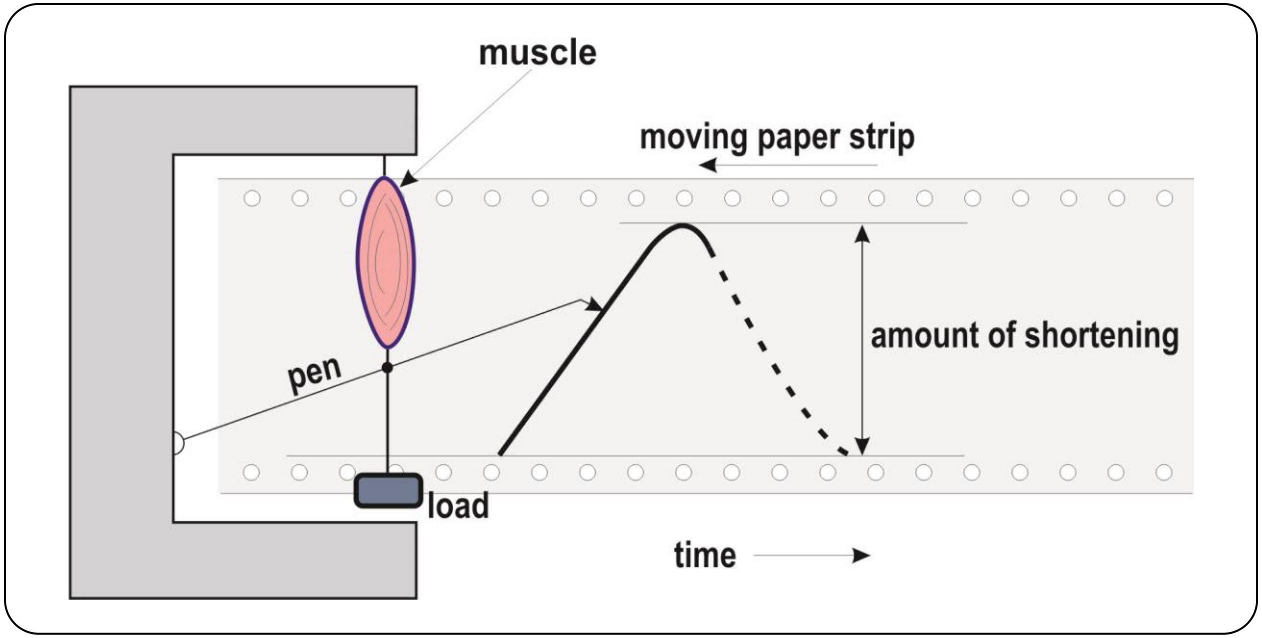
- ISOTONIC
- ISOMETRIC
- AUXOTONIC

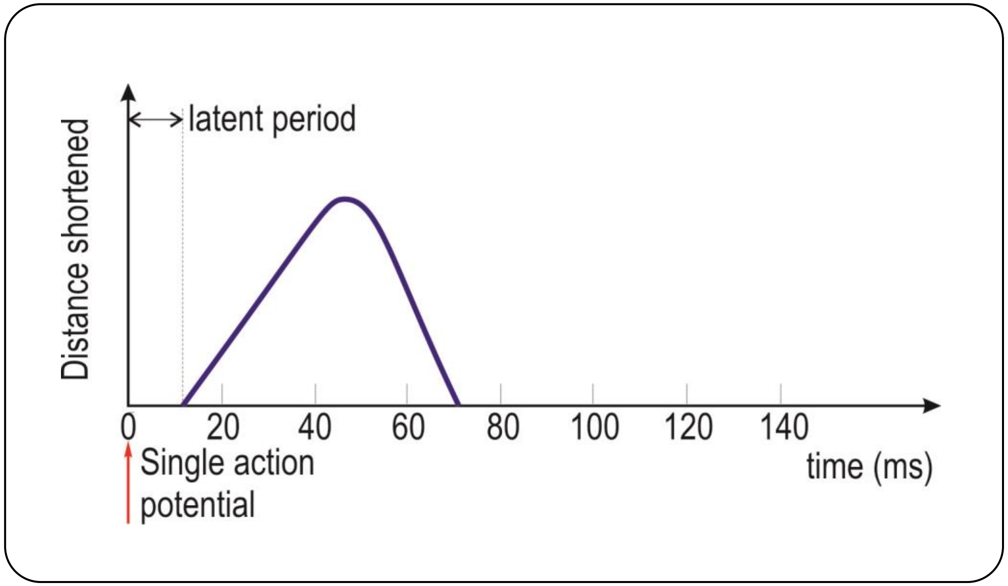
A contraction occurring under conditions in which the load on a muscle remains constant but the muscle length is changing is said to be isotonic (constant tension)

Recording of Isotonic Contraction

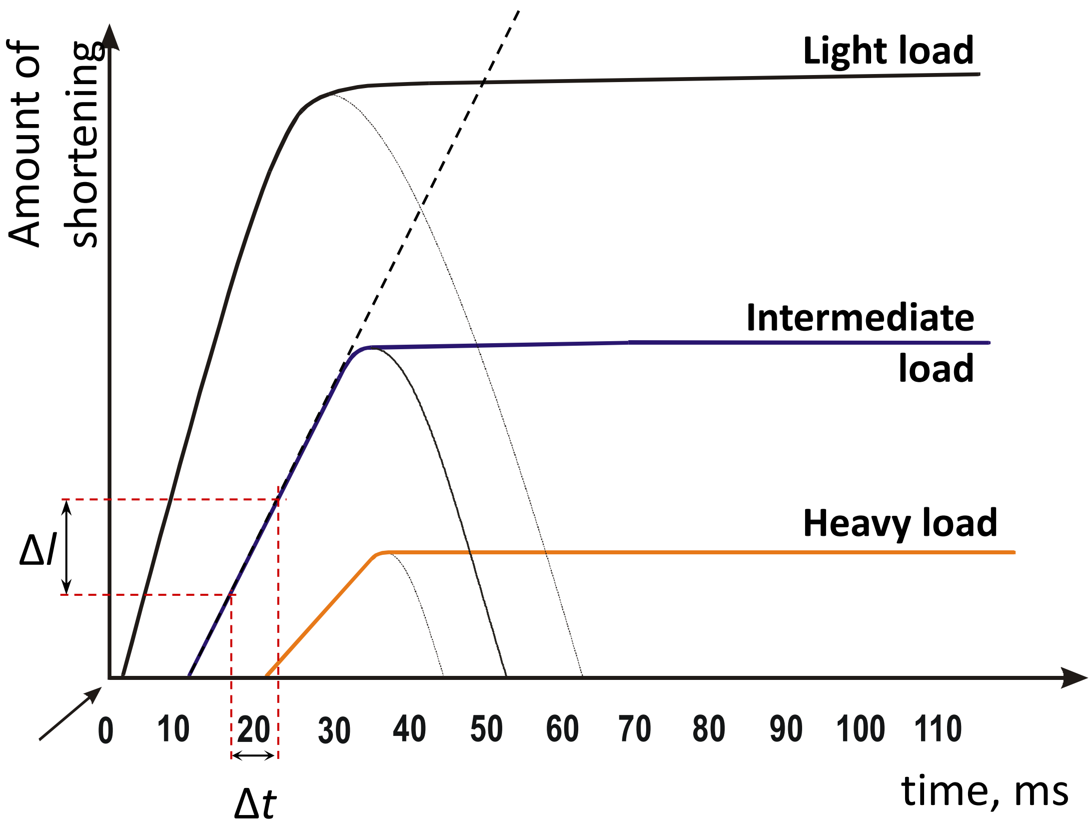


Isotonic Twitch





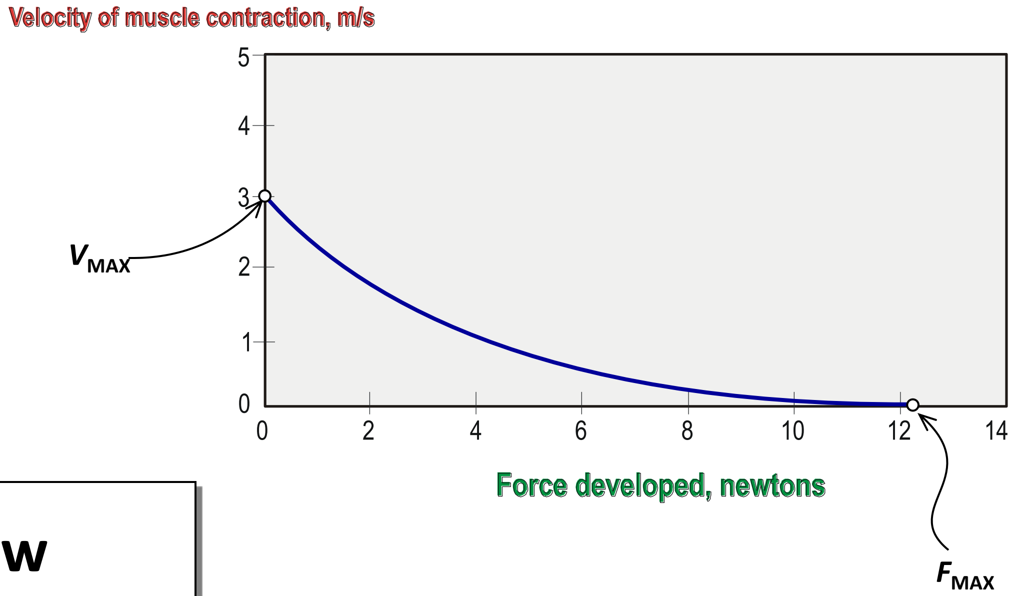
The Isotonic Experiment - Results



$$\frac{\Delta l}{\Delta t} = \text{velocity}$$

The Velocity of Muscle Contraction vs Force Developed by Contracting Muscle:

THE VELOCITY – FORCE RELATIONSHIP



The Hill law

$$(F + a)\cdot v = (F_{max} - F)\cdot b$$

F - actual force a muscle develops,

F_{max} - maximum force a muscle is able to develop

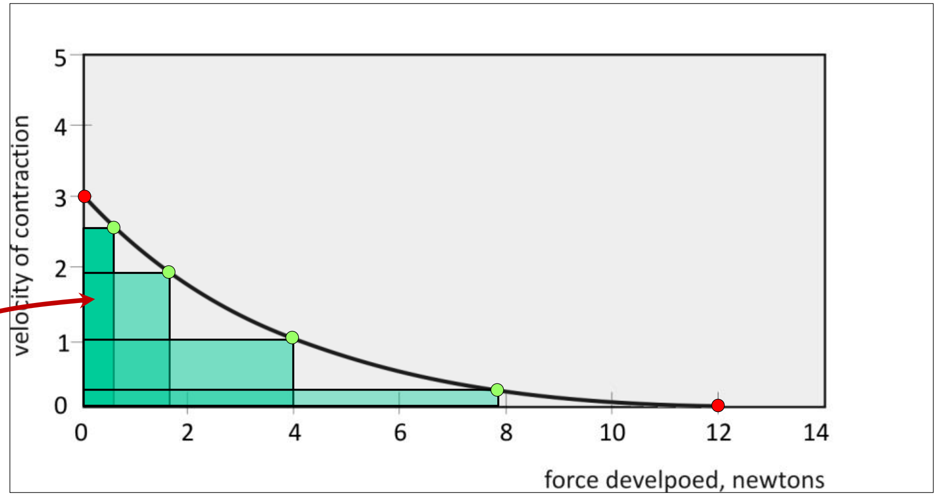
v - velocity of contraction (shortening)

a, b - constants.

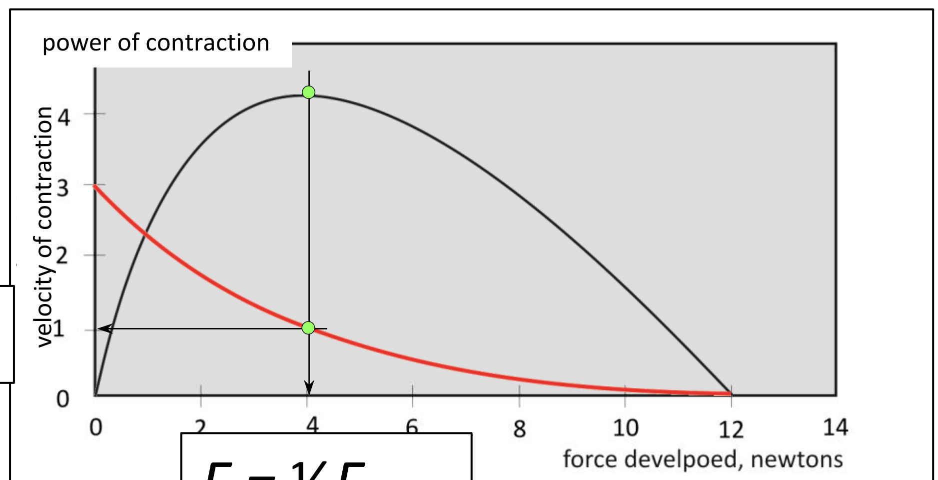
How to estimate power of contraction?

THE POWER – FORCE RELATIONSHIP

$P = F \cdot v$



$v = \frac{1}{3} v_{max}$

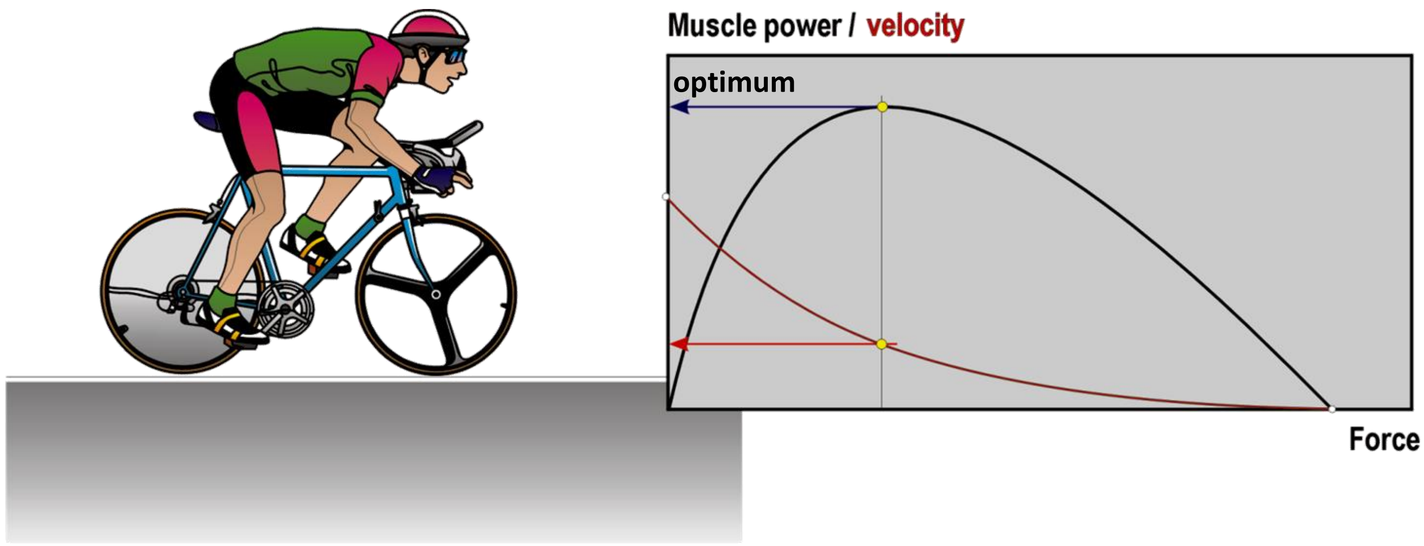


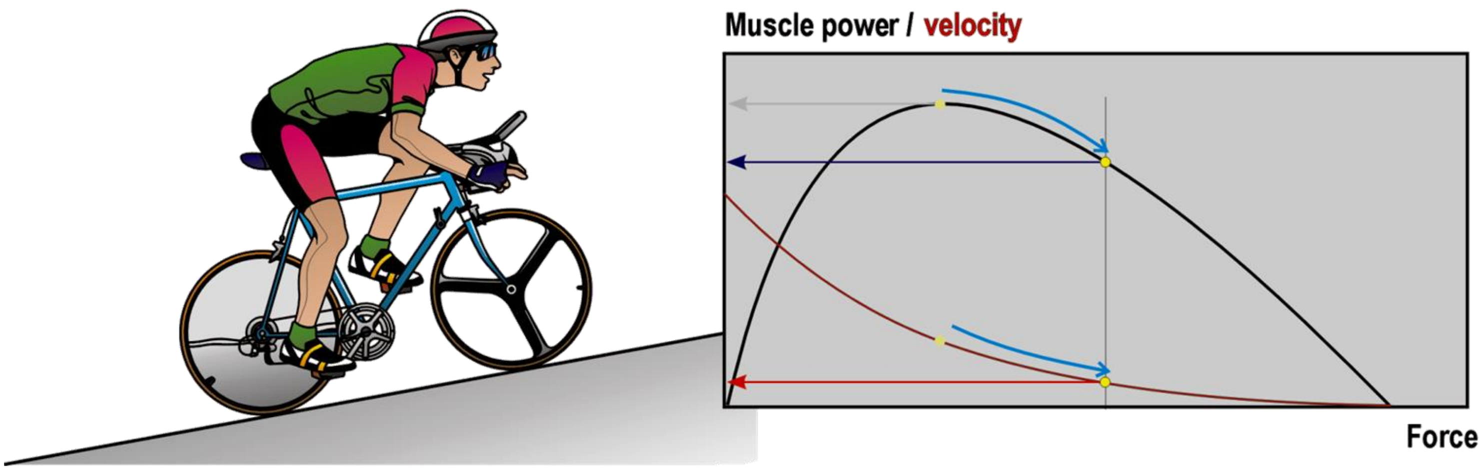
$F = \frac{1}{3} F_{max}$

P = 3.6 W

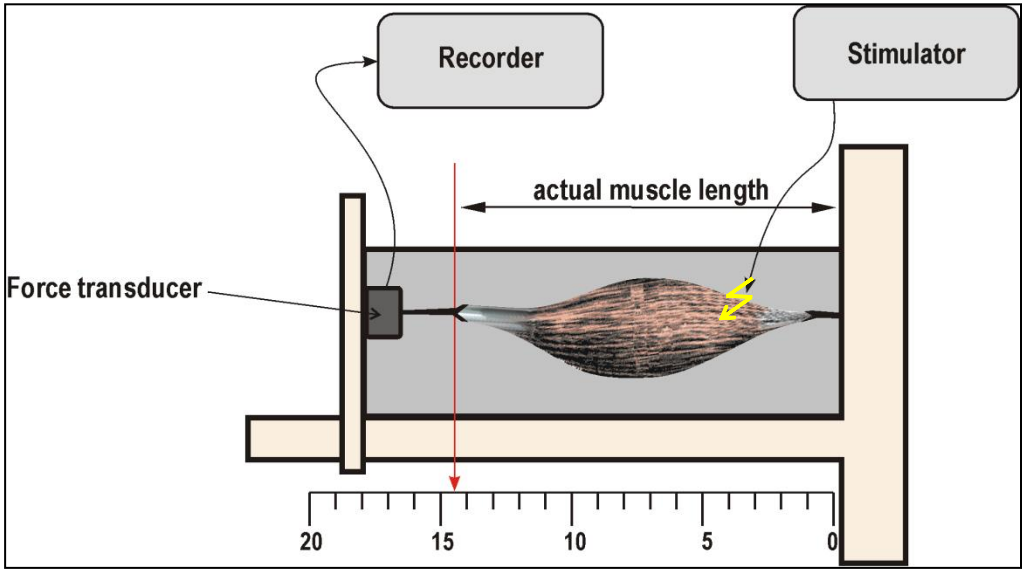
$$P_{max} = \frac{1}{3} v_{max} \cdot \frac{1}{3} F_{max} \approx 0.1\, v_{max} \cdot F_{max}$$

A cyclist


Muscle power / velocity
optimum
Force

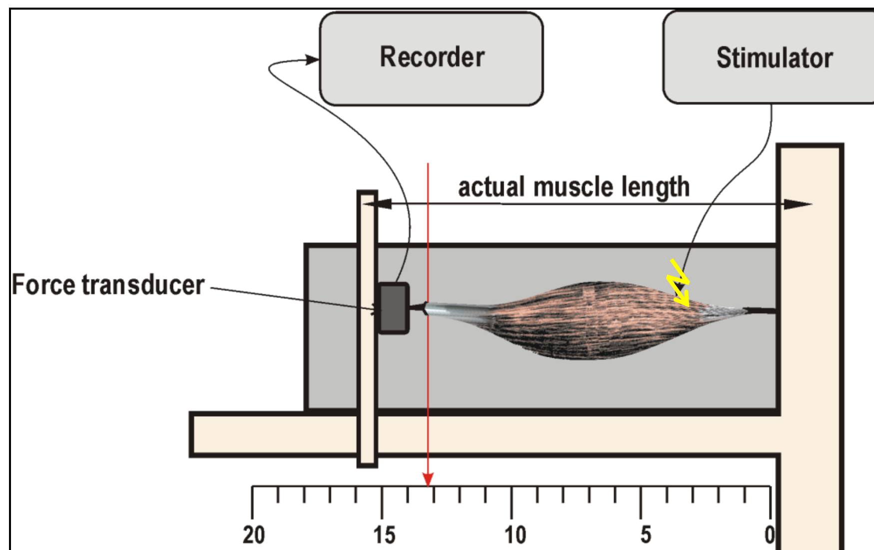

Muscle power / velocity
Force

Recording of Isometric Contraction

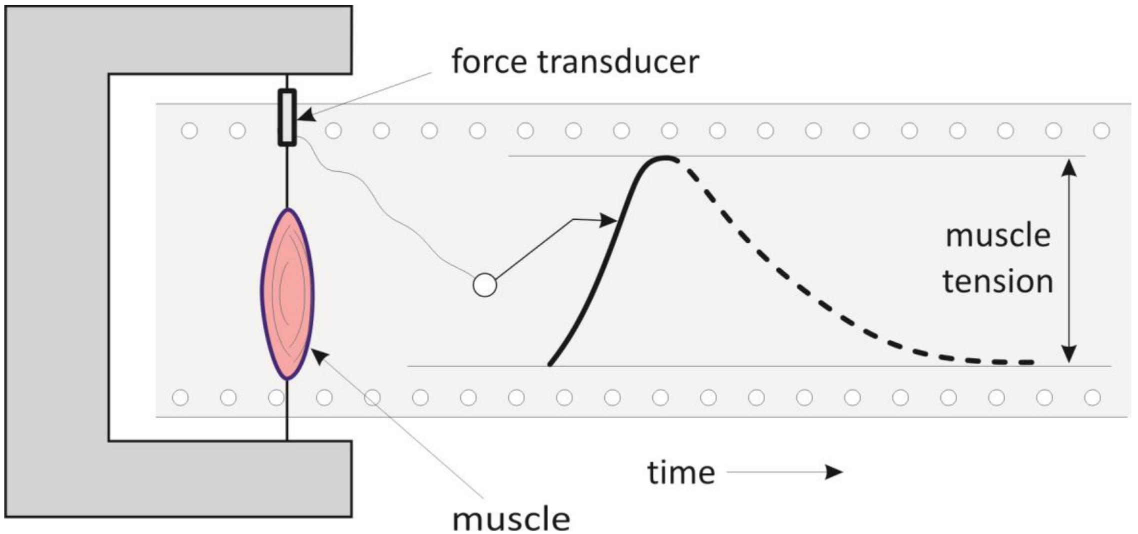


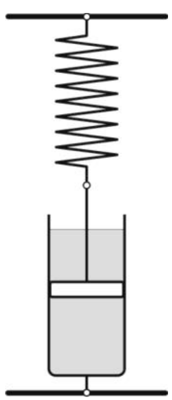
When a muscle develops tension but does not change length, the contraction is said to be <u>isometric.</u>

stress-force relationship

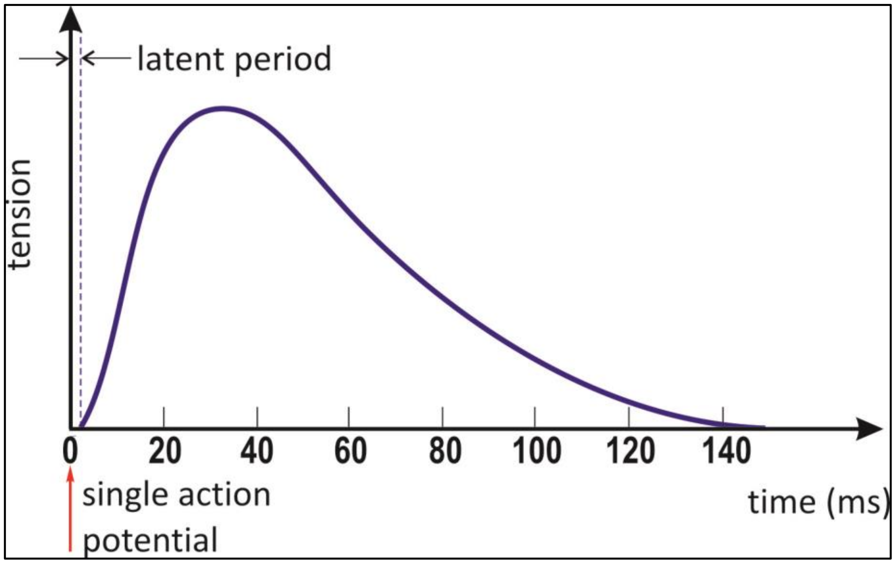


Isometric Twitch

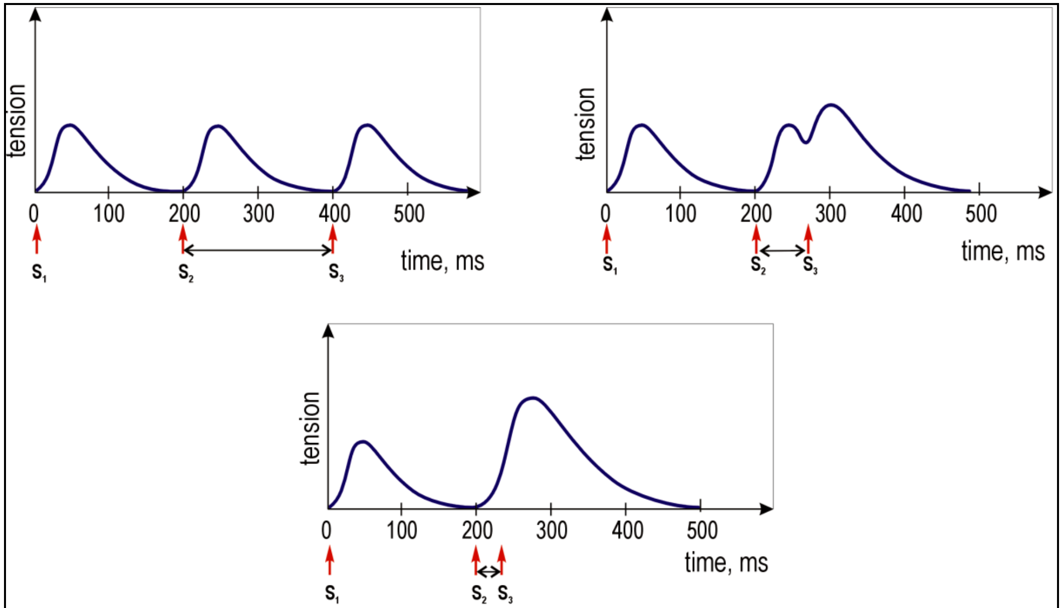




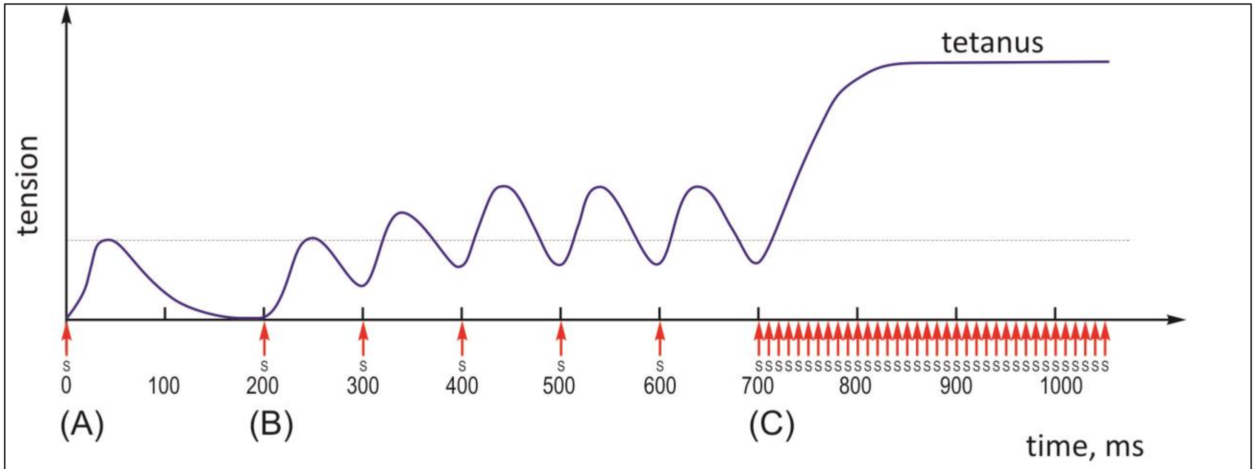
MAXWEL ELEMENT



Summation of Isometric Contractions



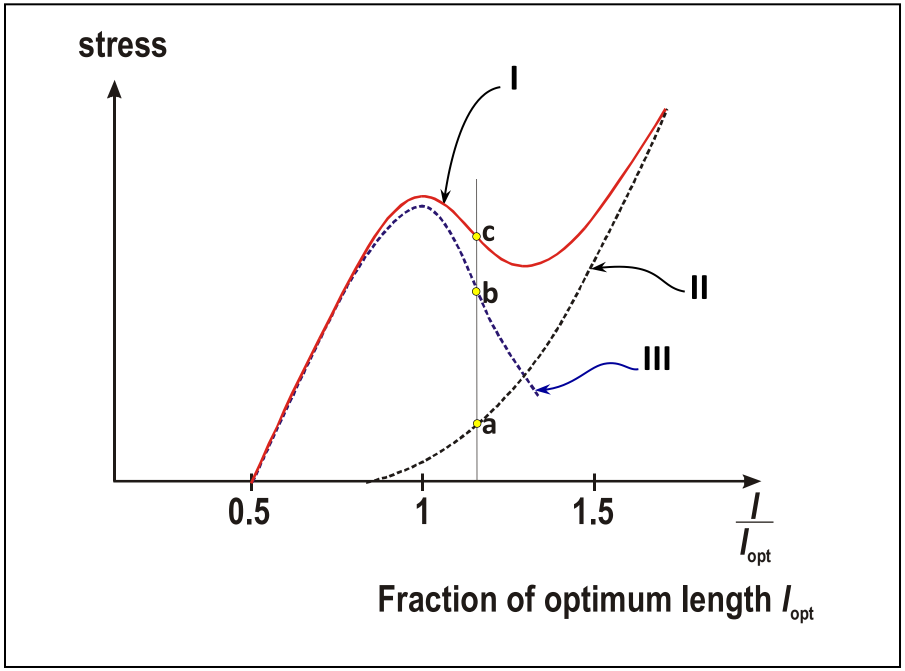
Summation of isometric contractions produced by shortening the time between stimulus S_2 and S_3



Isometric contraction produced by a single twitch (A), compared with those produced by 10 stimuli per second (B) and 100 stimuli per second (C).

STRESS (FORCE) – LENGTH RELATIONSHIP

ISOMETRIC CONDITIONS



Total force developed (curve I) by the muscle is the sum of:

- the passive force component due to stretching of connective tissue within the muscle (curve II)

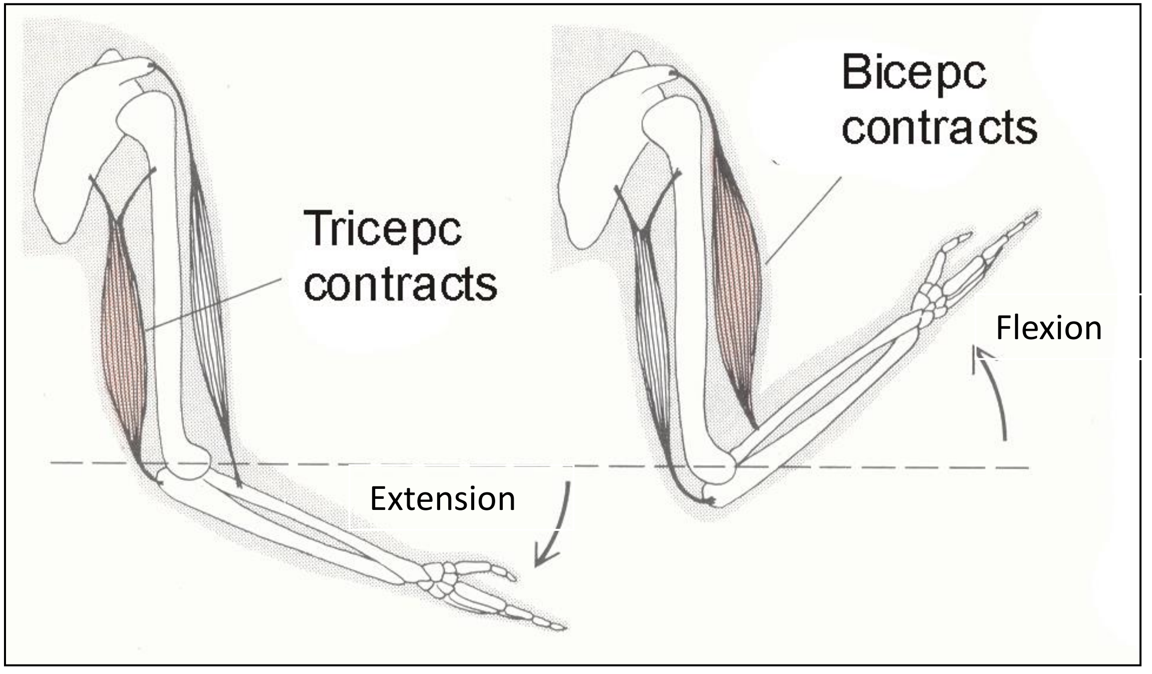
and

- the active force component developed in response to a stimulus (curve III)

Lever action of muscles and bones

A contracting muscle exerts a force on bones through its connecting tendons. When the force is great enough, the bone moves as the muscle shortens (!).

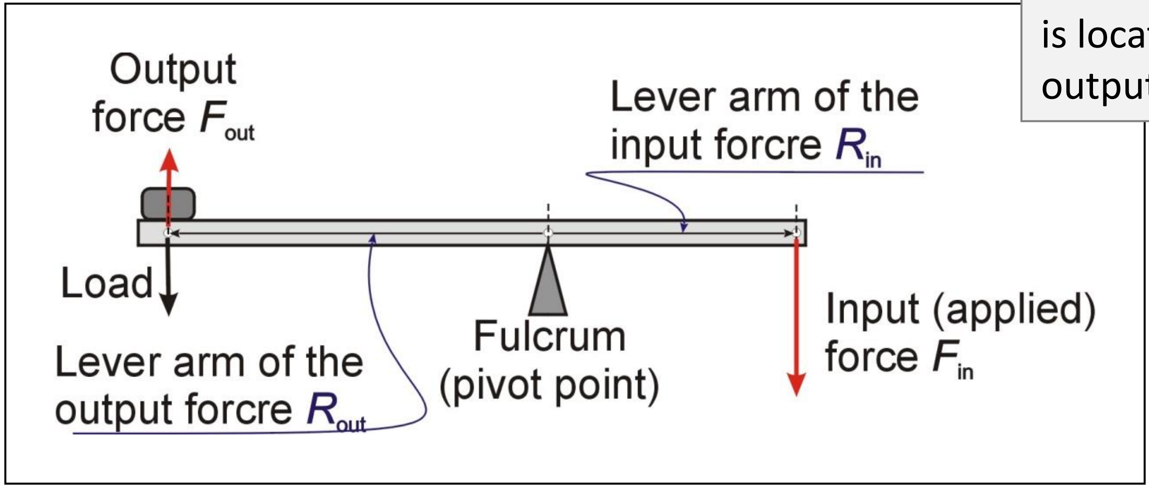
A contracting muscle exerts only a pulling force, so that as the muscle shortens, the bones to which it is attached are pulled toward each other.



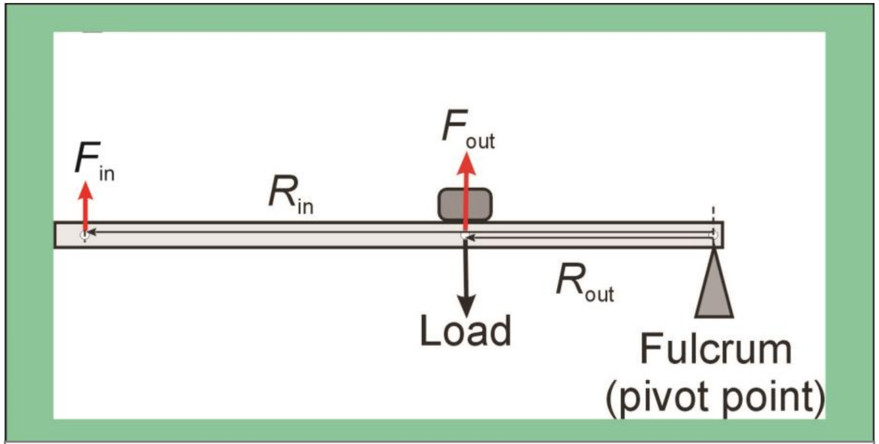
Lever models

- First-order (class 1) lever

A first-class lever is a lever in which the fulcrum is located in between the input force and the output force .



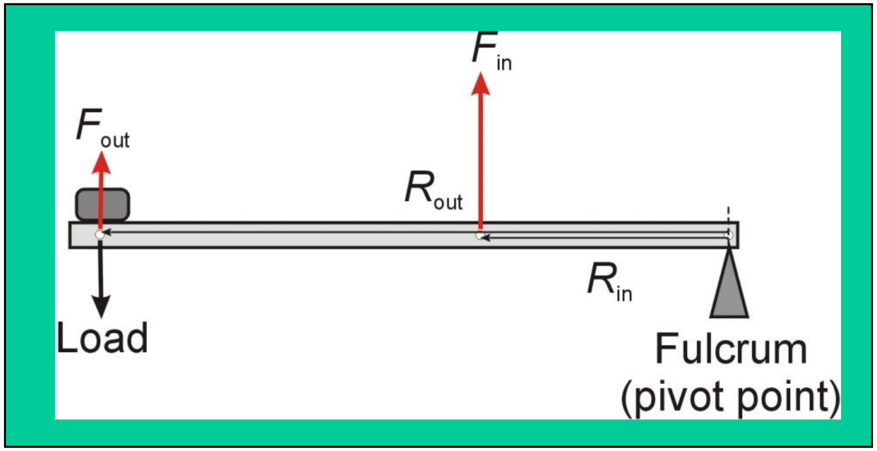
- Second-order (class 2) lever



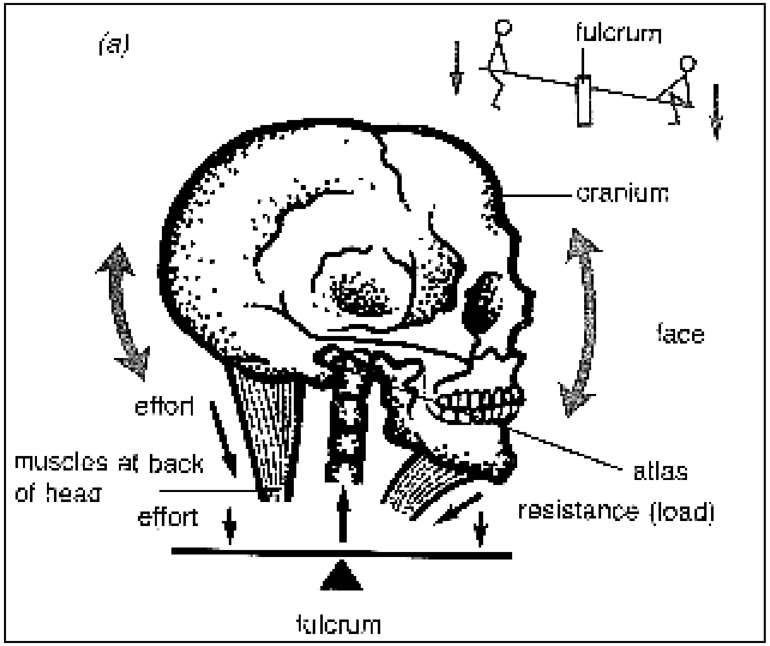
A second-class lever: the input force is applied at the far side of the beam, the output force is located in between the end and the fulcrum.

A third-class lever: the input force is applied closer to the fulcrum then the load (or the output force).

- Third-order (class 3) lever

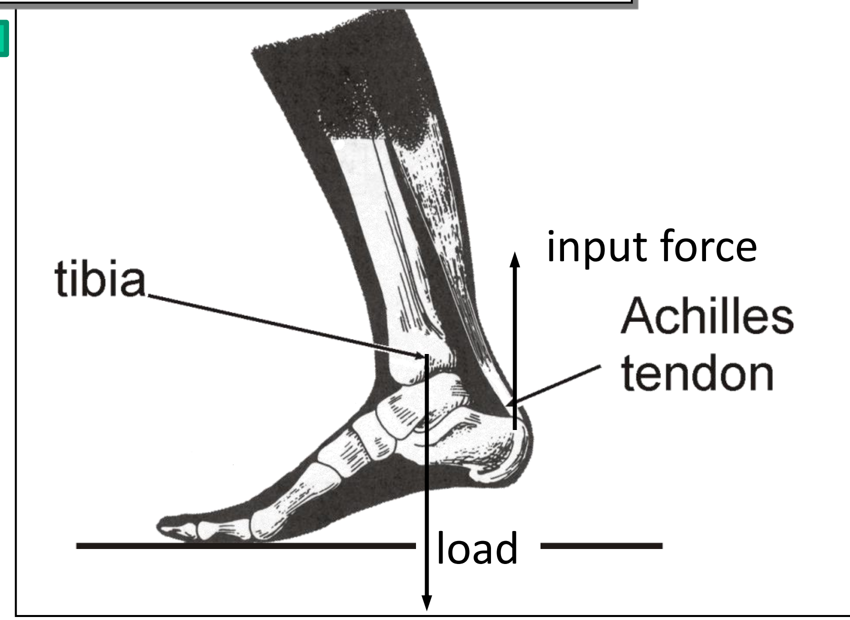


Examples

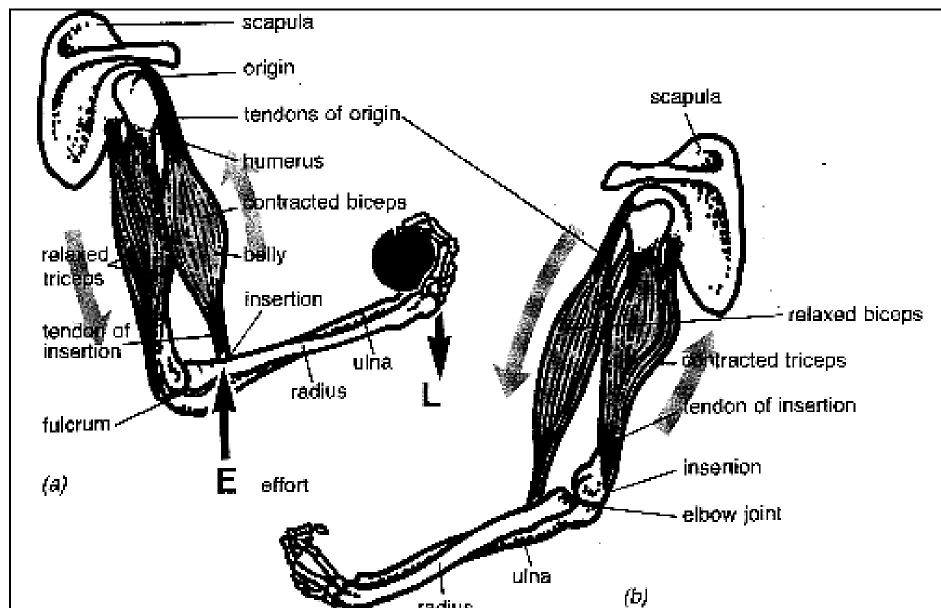


- First-order (class 1) lever

- Second-order (class 2) lever



- Third-order (class 3) lever

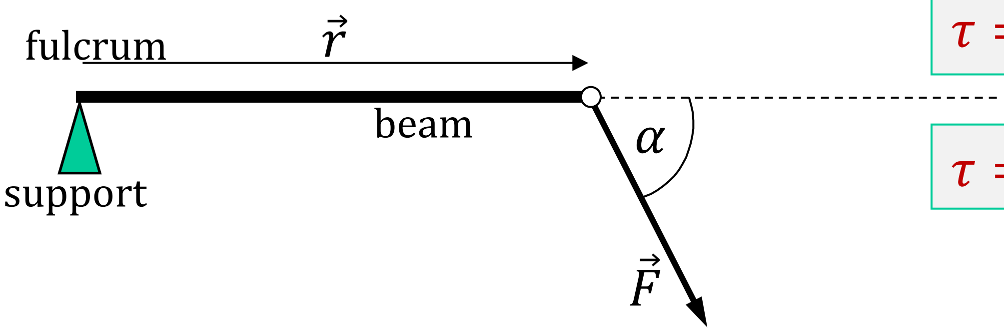


Torque

To make an object start rotating about an axis *requires a force*.
The imortant things are:
- the direction of the force,
- the magnitude of the force,
- where it is applied.

The torque τ is defined as the vector product of the applied force F and the distance r from fulcrum.

$$\vec{\tau} = \vec{r} \times \vec{F}$$



$$\tau = r \cdot F \cdot \sin(\vec{r}, \vec{F})$$

$$\tau = r \cdot F \cdot \sin \alpha$$

THE LEVER EQUATION

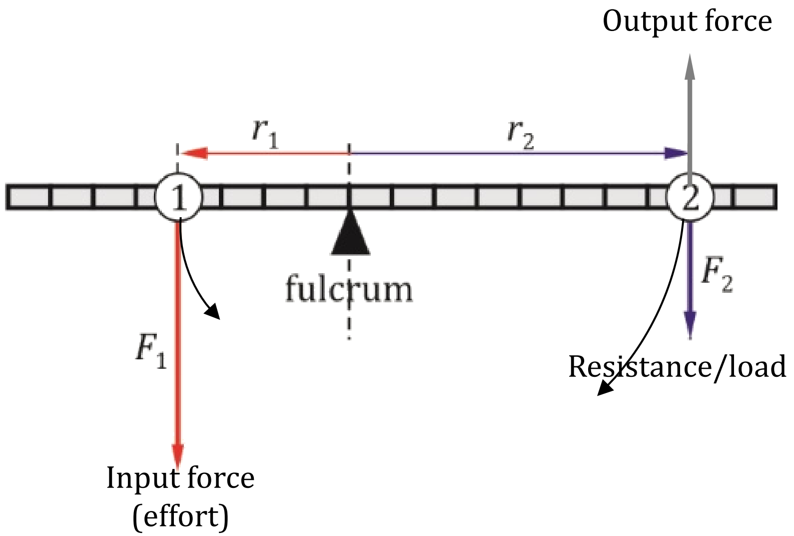
$$\vec{\tau}_{F_1} + \vec{\tau}_{F_2} = 0$$

$$\overrightarrow{r_1} \times \overrightarrow{F_1} + \overrightarrow{r_2} \times \overrightarrow{F_2} = 0$$

$$r_1 \cdot F_1 + (-\, r_2 \cdot F_2) = 0$$

$$r_1 \cdot F_1 = r_2 \cdot F_2$$

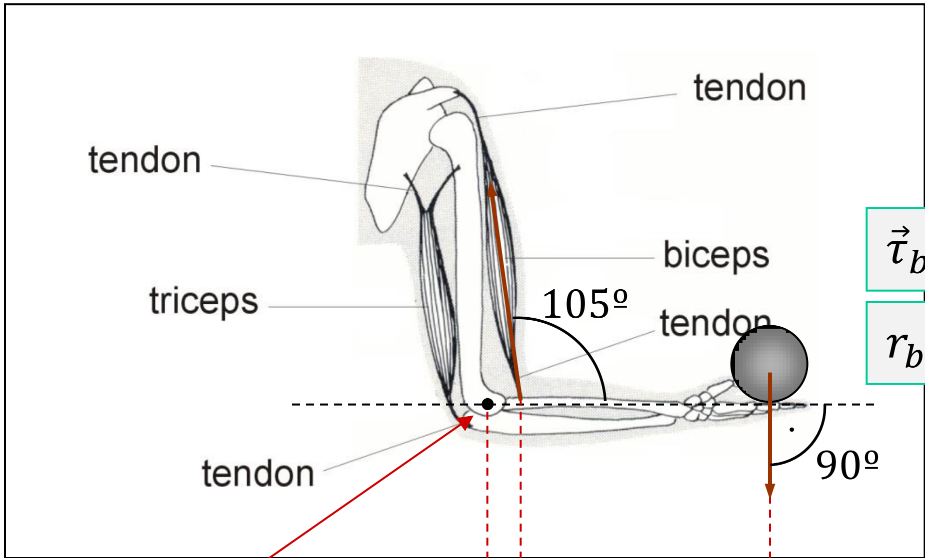
Example: balance of the first order lever



Mechanical advantage:

$$\boldsymbol{MA = \frac{output\ force}{input\ force} = \frac{F_2}{F_1} = \frac{r_1}{r_2}} = 0.5\ -disadvantage$$

Biceps torque



The forearm will be in mechanical equilibrium when the torque of biceps force (τ_{biceps}) is equal to the torque of the load τ_{load} that forearm supports:

$$\vec{\tau}_{biceps} + \vec{\tau}_{load} = 0$$

$$r_{biceps} F_{biceps} \sin 105° - r_{load} F_{load} \sin 90° = 0$$

Load_{max} = ?

According to Hill the maximum tension force exerted by a muscle is about 50 N per 1cm^2 of its cross section. Since the cross section of average biceps is about 50 cm^2 the maximum force equals:

$$F = 50\ \text{N/cm}^2 \times 50\ \text{cm}^2 = 2500\ \text{N}$$

$$F_{load} = \frac{r_{biceps} \cdot F_{biceps} \cdot \sin 105°}{r_{load} \cdot \sin 90°} = \frac{0.040\ \text{m} \cdot 2500\ \text{N} \cdot 0.96}{0.40\ \text{m} \cdot 1} = 240\ \text{N}$$

→ 24 kg

Disdvantage: The system works in mechanical disadvantage since the force developed by the muscle itself is considerably greater: (F = 2500 N → 250 kg)

Advantage: Analysis of the movement of the forearm lever shows that if the muscle shortens for instance by 1 cm, hand moves by about 10 cm.

$$\omega_{m.ins.} = \omega_{palm}$$

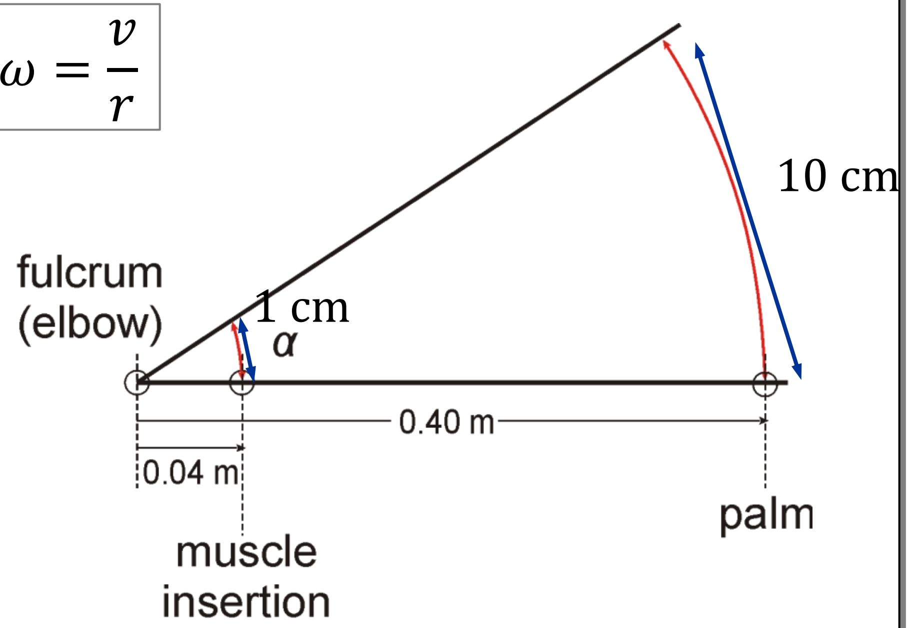
$$\frac{v_{m.ins.}}{r_{m.ins.}} = \frac{v_{palm}}{r_{palm}}$$

$$\frac{v_{palm}}{r_{m.ins.}} = \frac{r_{palm}}{r_{m.ins.}} = \frac{0.10\ \text{m}}{0.004\ \text{m}} = 10$$

$$v_{palm} = 10 \times v_{m.ins}$$

$$\omega = \frac{\Delta\alpha}{\Delta t}$$

$$\omega = \frac{v}{r}$$

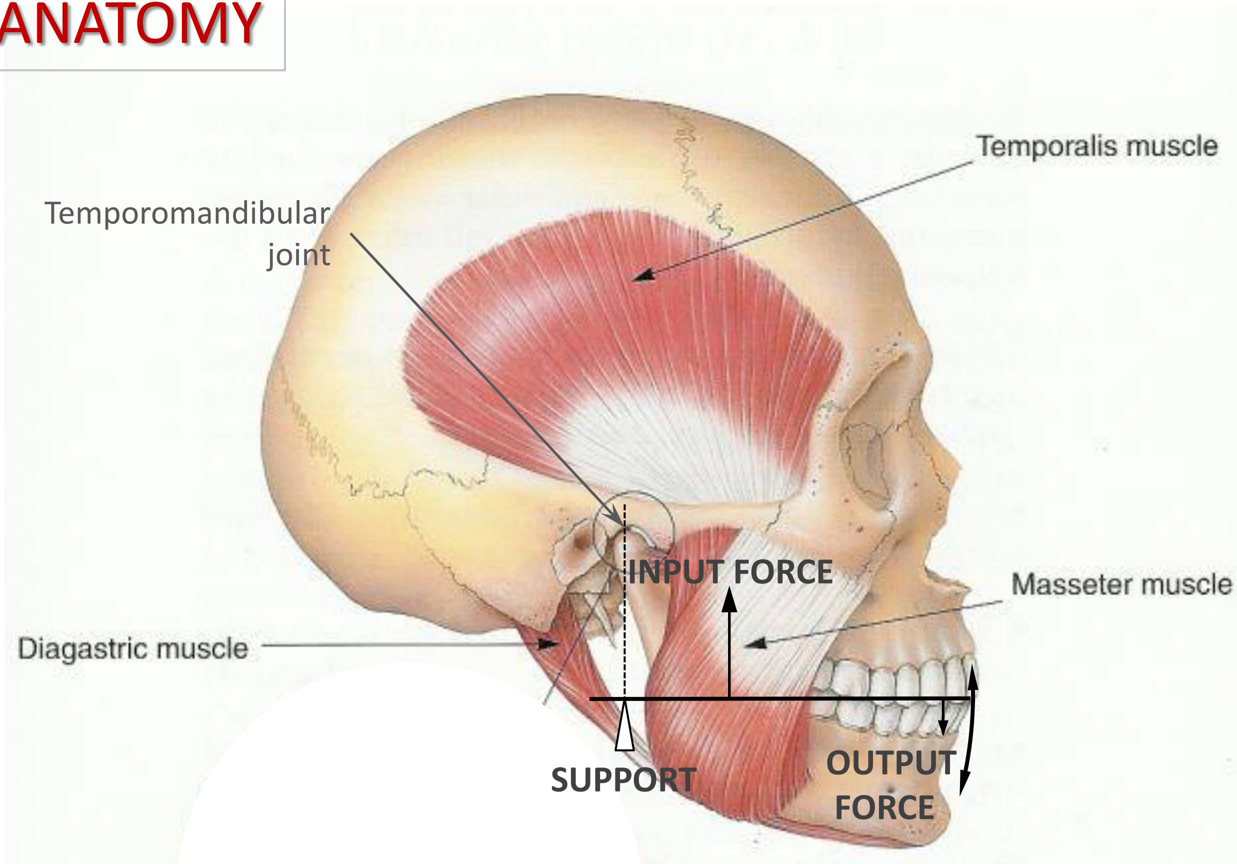


THE VELOCITY AT WHICH HAND MOVES IS TEN TIMES GREATER TAN THAT OF MUSCLE SHORTENING.

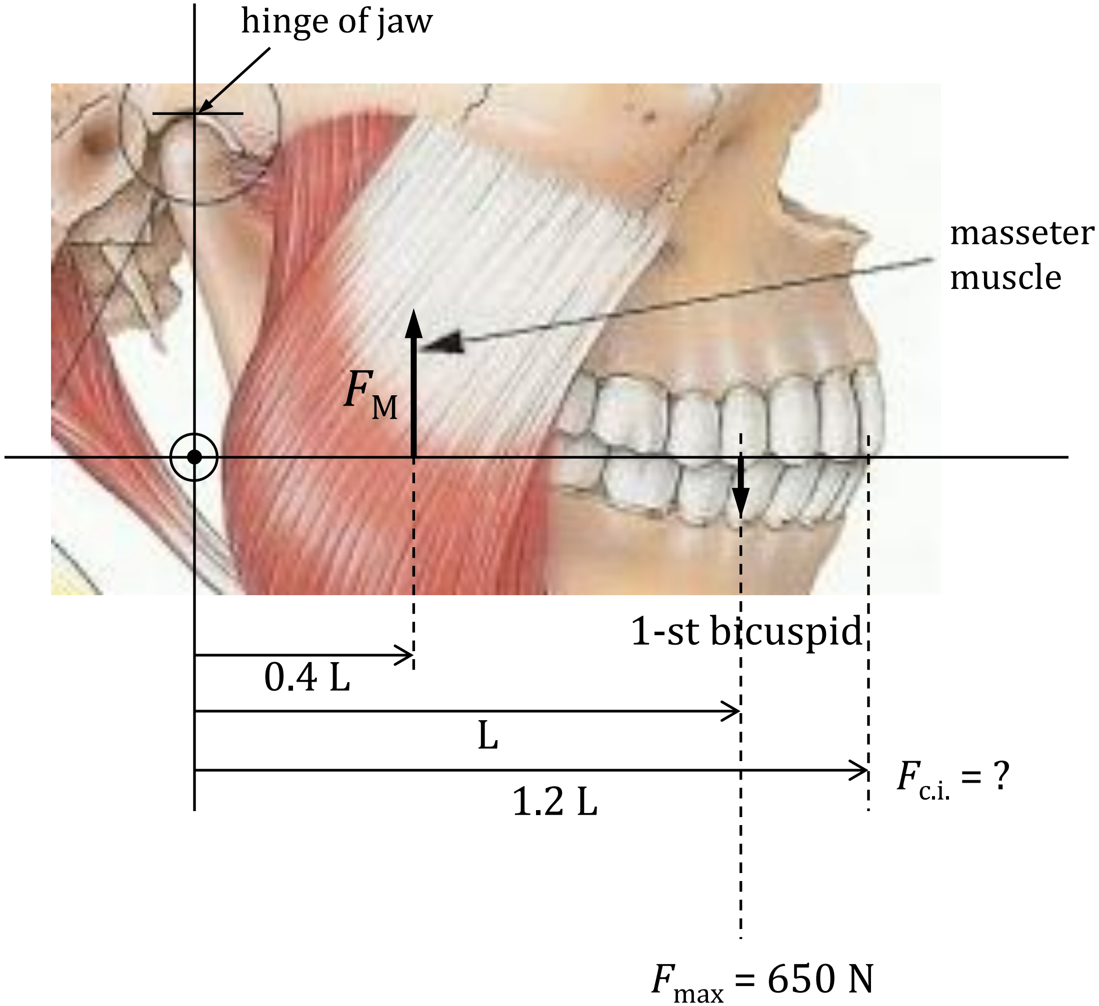
❖ THE LOST IN ABILITY OF CARRYING WEIGHT IS COMPENSATED BY THE GAIN OF THE SPEED OF MOVEMENT.

FORCES IN TEETH

ANATOMY



THE THIRD-ORDER LEVER



The masseter force F_M:

$$F_M \times 0.4L = 650\ \mathrm{N} \times L$$

$$F_M = \frac{650\ N \times L}{0{,}4\ L} = 1625\ N$$

Calculate force on the central incisors.

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Sliding-past Mechanism