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Introduction to Orthopaedic Biomechanics

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Aims of this talk include

- The basic methods of analysing static equilibrium to discover the loads on joints and tissues;
- To demonstrate that the forces acting on internal structures, such as our joints, are much larger than the external forces acting on our bodies.
- Plus a glimpse of real complexities…

Static Equilibrium

- This analysis is based on Newton's laws,
- That "every action has an equal and opposite reaction",
- That "an object will persist in its state of motion or rest unless acted upon by a resultant force"
- That "when a force acts on an object it will cause it to accelerate in proportion to the size of the force and inversely to its mass".

There are several areas of mechanical analysis

- Statics: in which we analyse the state of equilibrium without reference to motion;
- Kinematics: in which we analyse the motion without reference to the forces acting;
- Dynamics: in which we analyse both the motion and the forces affecting the motion.

For static equilibrium, we must analyse both linear and rotational effects together:

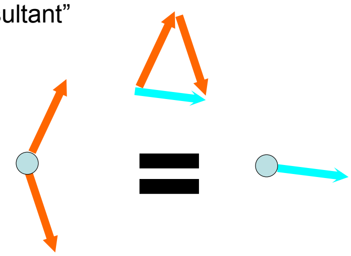
- Forces cause linear translations;
- Moments cause rotations.
- Both are *vectorial* variables: they must be defined by how large they are and also by their direction.
- Scalar variables, such as mass, do not have any inherent directionality.

Force

- Unit: the Newton.
- Defined as: The amount of force which, when acting on a body with a mass of 1 kg, will cause it to accelerate at a rate of 1 ms^{-2}
- N.B.: Weight is a force, not a mass, due to the action of gravitational acceleration on the mass, so a mass of I kg has a weight of 9.81 N!

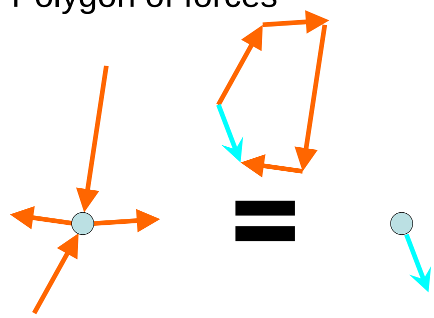
Combining Forces by adding force vectors

- "Resultant"



So, what force is needed to restore equilibrium?

Polygon of forces



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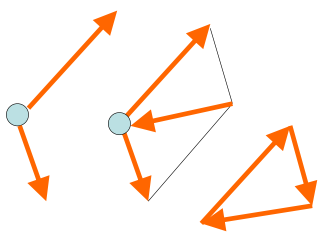


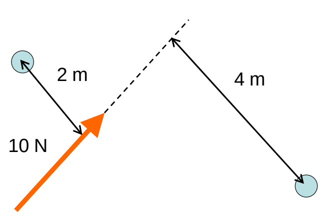
For equilibrium, the addition of all the force vectors has zero resultant force: the arrows lead back to the origin!

3 forces lead to a Force Vector Triangle if they are in equilibrium.

Turning effects: Moments

- Moments, or torques, cause a turning effect about an axis (e.g. a joint axis).
- The units of a moment are Nm.
- Thus, for a given force (N), its moment (Nm) increases as its distance (m) from the axis increases.
- It is vectorial: clockwise vs anticlockwise

Moments: The magnitude of the force times the perpendicular distance from the line of action of the force to the axis.

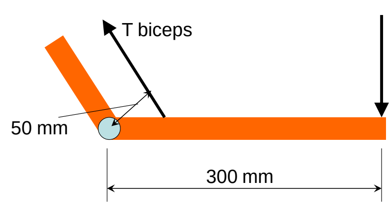


What is the moment of the 10 N force about this axis?

The force exerts a moment of + 40 Nm about this axis

We must define + and -. Here clockwise is +. So this force causes a moment of – 20 Nm about the axis

For rotational equilibrium, all the moments acting about an axis must sum to zero



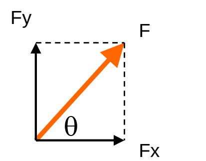
(NB: weight is a force due to gravity, in Newtons, so 80 N was caused by a mass of approx 8 kg!)

For equilibrium: +(80 x 0.300) – (T biceps x 0.050) = 0.

So T biceps = 80 x 0.300 / 0.050 = 480 N

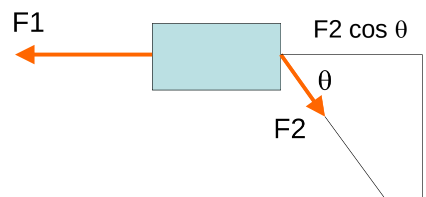
To ensure equilibrium, we most often examine the equilibrium of forces and also of moments acting on a body.

To simplify matters, we usually examine the force components acting in orthogonal directions: e.g. horizontal and vertical, after resolving the forces into these components:



Fx = F cos θ; Fy = F sin θ

Horizontal equilibrium: what force F2, acting in the direction shown, will give equilibrium?

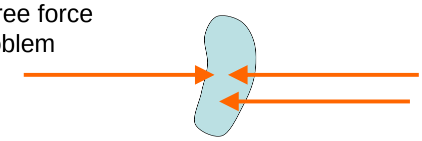


So, if cos θ = 0.67, F2 = 1.5 F1.

This explains Q:PT tension ratio

Special Cases in Equilibrium

- One force problem
- Two force problem
- Three force problem

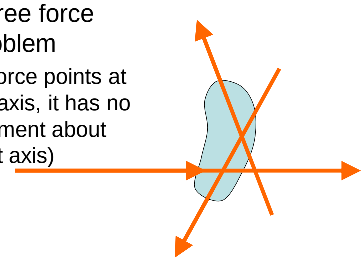


So 2 forces must be colinear!

Special Cases in Equilibrium

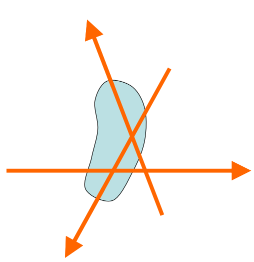
- Three force problem

(If a force points at an axis, it has no moment about that axis)

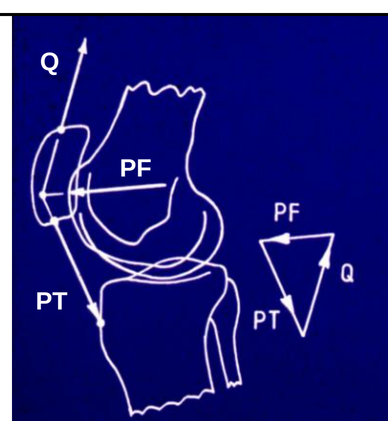


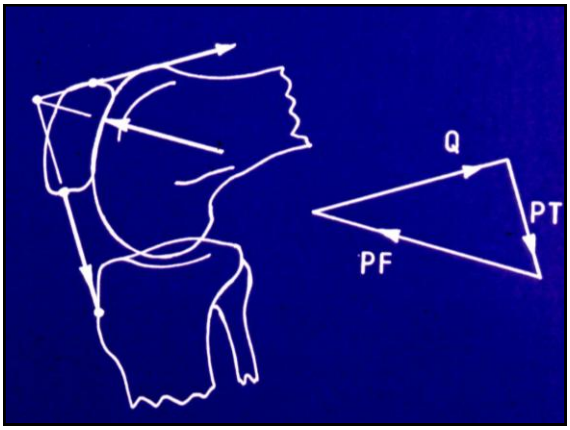
Special Cases in Equilibrium

- Three force problem



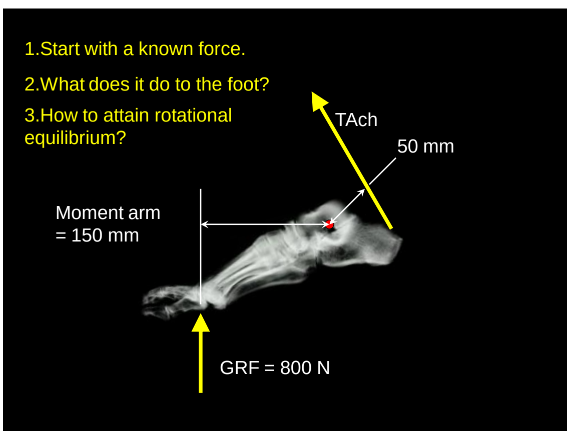
So 3 forces must intersect at a point!

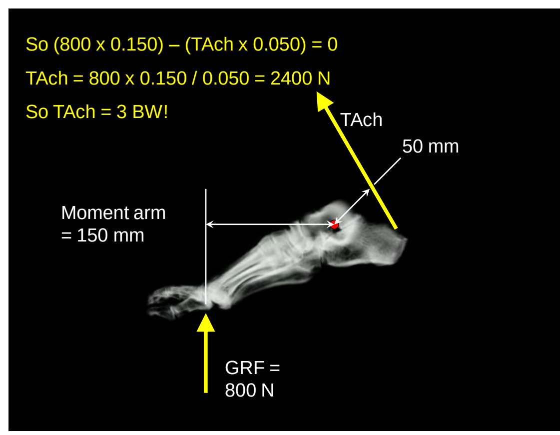


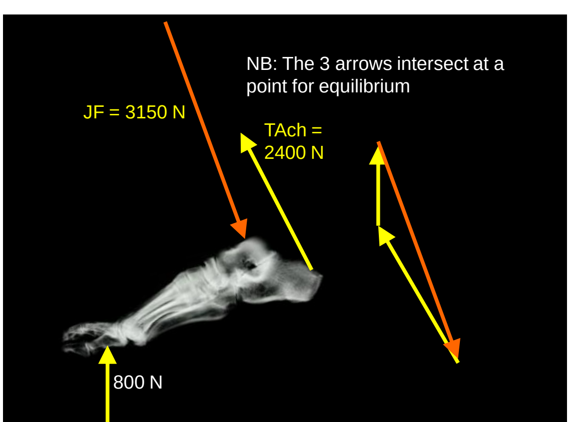


Calculate the magnitude and direction of the tibio-talar joint force

We start by drawing the foot in isolation; This is called a ***'Free-body diagram'***. It doesn't matter what forces are inside the free-body, all we need to do is to analyse all the forces and moments acting on it.

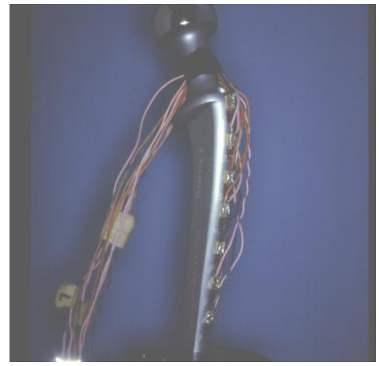






So far, we have only dealt with very simple cases: greater complexity arises in-vivo:

- 3-D reality: need to simultaneously ensure equilibrium about x,y,z axes;
- Many co-operating muscles – how to assign tensions to each of them?
- Motion entails forces resulting from acceleration of masses such as limb segments: inertial effects.



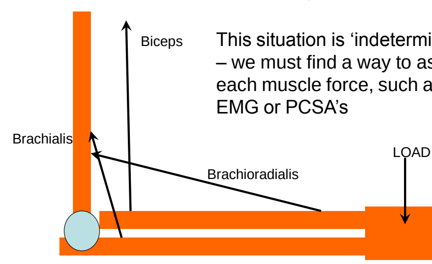
The reduced head-stem offset did reduce the abductor muscle forces and the bending moment acting on the stem.

But it also reduced the moment arms of the muscles controlling internal/external rotation.

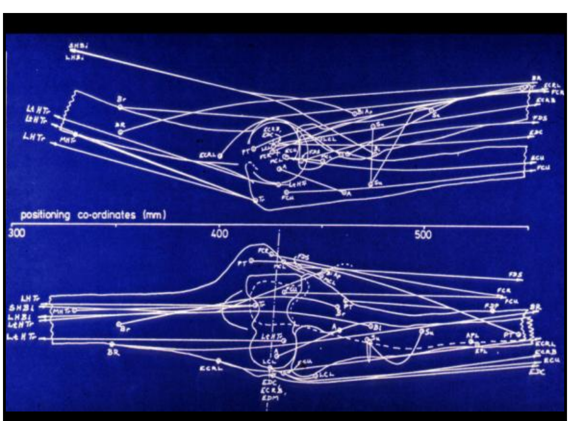
So the forces acting in the AP direction increased, and the reduced-offset stem fractured in AP bending!

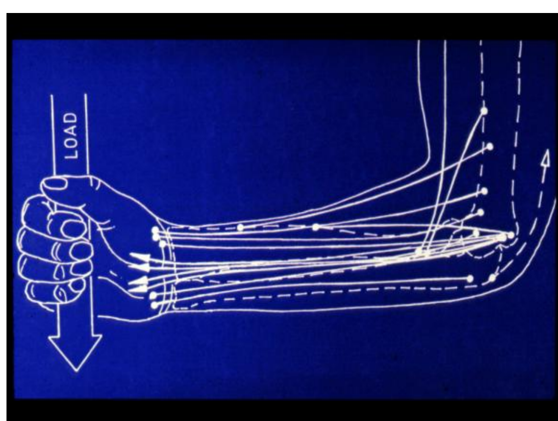
Elbow flexion analysis

This situation is ‘indeterminate’ – we must find a way to assign each muscle force, such as EMG or PCSA’s



Complexity increases: hand grasping, wrist stability, triceps antagonism for elbow stability, forearm rotation equilibrium





Typical Gait Analysis Laboratory

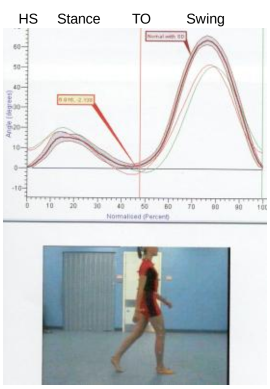
Force Plates

(Kinetics)

Movement Analysis

(Kinematics) with multiple cameras

Electromyography (EMG) muscle activity

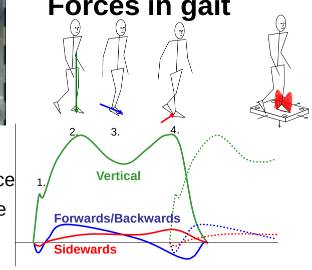


Gait analysis

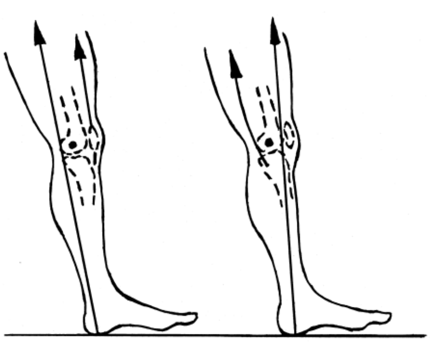
- Knee joint flexion graph
- Subject filmed with targets on limbs

Capabilities of Force Plates

Forces in gait



1. Heel Strike
2. Weight Acceptance
3. Mid Stance Phase
4. Push Off



Thank you!