I. Some tools for Biomechanics

-- Review of some useful physics

Introduction to Biomechanics

2008/10/1

1

(1) The basics

2

Units– Use SI system

1. Fundamental units are:

   kg (mass), m (distance), and sec. (time)

2. Prefixes

giga-	(G)	a billion (U.S.) times	10^9 X
mega-	(M)	a million times	10^6 X
kilo-	(k)	a thousand times	10^3 X
milli-	(m)	a thousandth of	10^{-3} X
micro-	(μ)	a millionth of	10^{-6} X
nano-	(n)	a billionth (U.S.) of	10^{-9} X

3. Prefixes in numerators, not denominators

3

Dimensions（因次）

Basic dimensions: mass (M), length (L), time (T)

Some dimensions for physical quantities:

Volume	L^3
Acceleration	LT^{-2}
Velocity	LT^{-1}
Force	MLT^{-2}
Work	ML^2T^{-2}
Power	ML^2T^{-3}
Pressure or stress	$ML^{-1}T^{-2}$

* Equations have to be dimensionally homogeneous

4

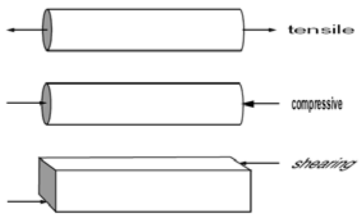
Physical variables

Quantity	Symbol	Origin	Dimensions	SI Units
Mass	m	(fundamental)	M	kilogram
Length	l	(fundamental)	L	meter
Time	t	(fundamental)	T	second
Area	S	∝* to length squared	L^2	square meter
Volume	V	∝ to length cubed	L^3	cubic meter
Velocity	v	length/time	LT^{-1}	meter/second
Acceleration	a	speed change/time	LT^{-2}	meter/second^2
Force	F	mass x acceleration	MLT^{-2}	newton
Momentum	mv	mass x velocity	MLT^{-1}	kg meter/second
Stress	σ	force/area	$ML^{-1}T^{-2}$	newton/meter^2 or
Pressure	p	force/area	$ML^{-1}T^{-2}$	pascal
Work	W	force x length	ML^2T^{-2}	joule
Power	P	work/time	ML^2T^{-3}	watt
Density	ρ	mass/volume	ML^{-3}	kg/meter^3

5

Stress (σ) = Force/Area

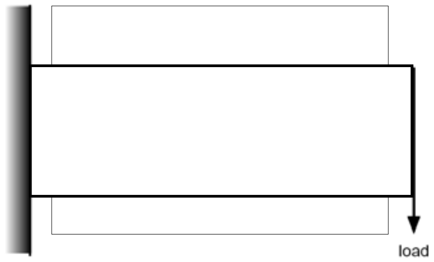
Three kinds of “material” stresses



6

"Structural" stress

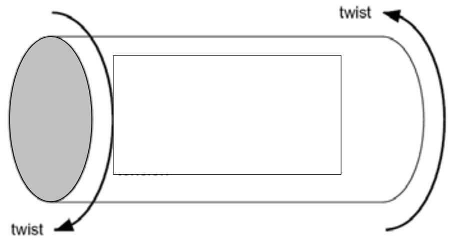
– flexural (bending)



7

"Structural" stress

– torsional (twisting)



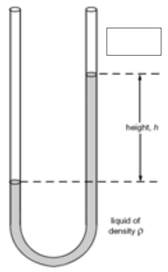
8

Pressure (p), same dimension & unit as stress

Stress: unidirectional

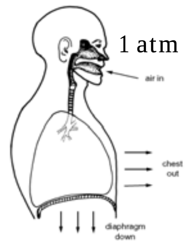
Pressure: omni-directional

$$\Delta p = \rho g h$$



9

Daily experience: how do we breathe?



"Gauge pressure"—pressure above atmosphere

10

Work (W) & Energy (E)

Work: $W = Fd$

Energy ≡ Capacity to do work

$$E = W = Fd$$

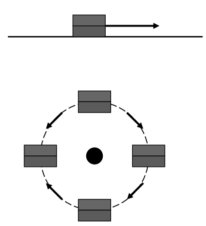
Kinetic energy $E = \frac{1}{2} m v^2$

Gravitational potential $E = mgh$

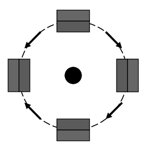
11

Motion

Translational motion



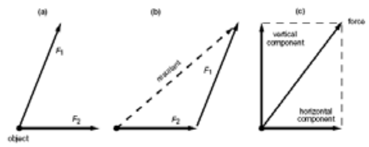
Rotational motion



12

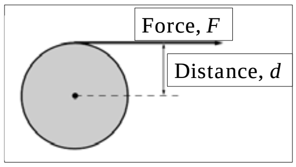
More about forces...

Forces as vectors



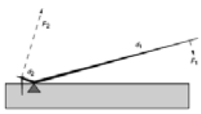
More about forces...

Moments of forces

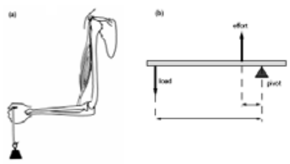


How effective a force induce rotation

= Moment of the force= Fd



Less force, greater distance



Muscle:

Greater force, less distance

More about forces...

Newton's Laws

Conservation Laws

In a properly isolated system...

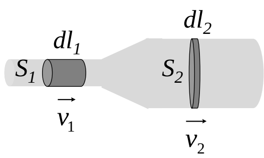
Mass
Momentum
Energy

} are conserved

But force, power are <u>not</u>

<u>Conservation of mass → fluid mechanics</u>

Incompressible flow in a rigid pipe...

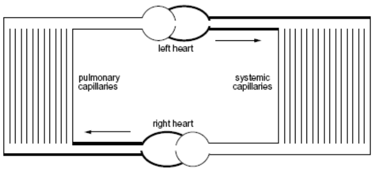


At the same time, volume in = volume out

$$\frac{S_1 dl_1}{dt} = \frac{S_2 dl_2}{dt}$$

$$S_1 v_1 = S_2 v_2$$ Principle of continuity

How many capillaries（微血管）are open?



19

States of Matter

Difference b/w solid, liquid, and gas?

	Compression	Tension	Shear
Solid	X	X	X
Liquid	X	X	
Gas	X		

} Fluids (Liquid, Gas)

20

(2) Dimensional Analysis & Dimensionless Numbers

21

Dimensions

Basic dimensions: mass (M), length (L), time (T)

Some dimensions for physical quantities:

Volume	L^3
Acceleration	LT^{-2}
Velocity	LT^{-1}
Force	MLT^{-2}
Work	ML^2T^{-2}
Power	ML^2T^{-3}
Pressure or stress	$ML^{-1}T^{-2}$

Equations have to be dimensionally homogeneous

22

Dimensional Analysis

Based on "Dimensional homogeneity"

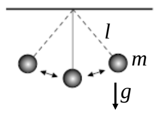
Langhaar (1951):

a phenomenon can be described by a dimensionally correct equation among certain variables

- Strength– little info → partial solution
- Weakness– no complete solution, no inner mechanism

23

Example: <u>Period (t) of a simple pendulum</u>



Our guess: t relates to m, l, g

$$t = k \cdot m^a l^b g^c$$

→ a, b, c?

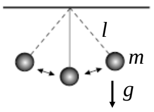
The analysis

$t \rightarrow T$
$m \rightarrow M$
$l \rightarrow L$
$g \rightarrow LT^{-2}$

$$T = k \cdot [M]^a [L]^b [LT^{-2}]^c$$

24

The result...



$$t = k \cdot m^0 l^{1/2} g^{-1/2}$$

or

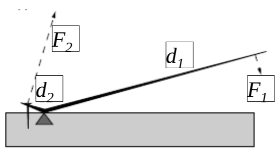
$$t = k \cdot \sqrt{\frac{l}{g}}$$

$$(t = 2\pi \sqrt{\frac{l}{g}})$$

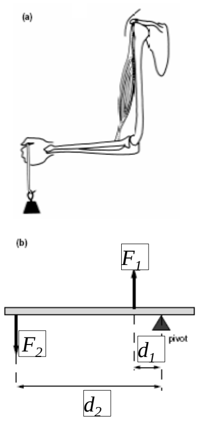
Dimensionless Numbers: FA or DA

The efficacy of a force amplifier:

Mechanical advantage or Force advantage (FA)



$$FA = \frac{F_{out}}{F_{in}} = \frac{F_2}{F_1} > 1$$



$$FA = \frac{F_{out}}{F_{in}} = \frac{F_2}{F_1} < 1$$

The efficacy of a speed amplifier:

Speed advantage or

Distance advantage (DA)

$$DA = \frac{d_{out}}{d_{in}} = \frac{F_{in}}{F_{out}} > 1$$

Dimensionless Numbers: *e*

The efficacy of doing work: Efficiency (*e*)

$$e = 100 \frac{W_{out}}{W_{in}}$$

** Be cautious what are used for input and output

Dimensionless Numbers: Ponderal index

How corpulent are you?

What would be a good dimensionless number?

Corporal index: $CI = \frac{m}{\rho h^3}$

Body mass index: $BMI = \frac{m}{h^2}$

... Non-dimensionless