BIOMECHANICS

A prosthetic hip joint should imitate normal hip joint activities as closely as possible. This means that the artificial hip should allow us to:

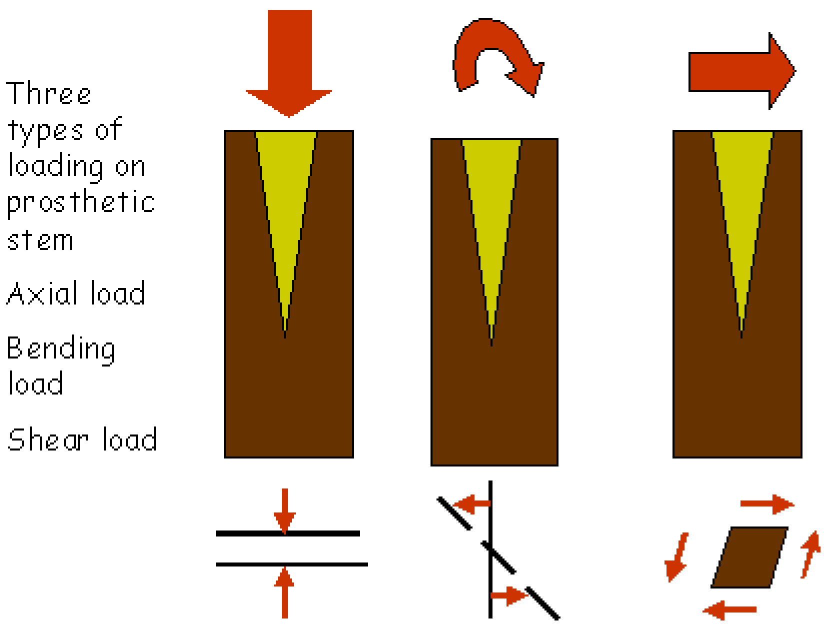
a. Stand without muscle effort
b. Walk with least energy expenditure
c. Sit normally

To perform a successful hip replacement, we need to know about the forces on the joint and the demands placed there of [look under biomechanics of hip: under Hip]

During quiet standing, three times the body weight act on each joint.
This is increased in arthritic hip due to shortened abductor lever arm.
The force could increase up to ten times in running.

Body weight vector goes posterior to the joint axis, so it acts on the joint in the sagittal plane to create a bending moment. This bending moment is increased in climbing stairs or getting up from a chair.

3 types of loading on the THR
Axial load
Bending load
Shearing load



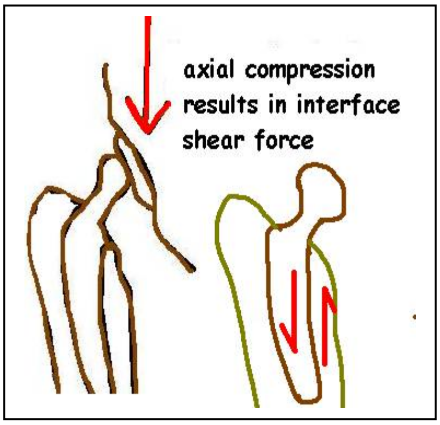
When a hip prosthesis is implanted in bone the bone-stem or bone-cement-stem becomes a composite structure. Although bone makes up most of the mass of the composite, the metal stem because of its high stiffness compared to bone takes up most of loading. This requires an understanding of some basic principles of composite loading

- The composite is subjected to the same forces
- The load is transferred in the composite via the interface
- In a bonded structure, this creates shear stress at the interface
- The force creates relative movement at the interface when it is not bonded
- If there is axial load on a composite, the stiffer it is, the easier it is to distribute the load, the less stiffer, the more of point loading.
- When subject to shear loading, load is transferred through the ends

When a hip prosthesis is implanted they are subject to the same forces:

Axial loading results in significant compressive force

This is transferred from the stem to the femur as a shear force, either directly in non-cemented prosthesis or via the cement in cemented prosthesis



Practical implications

Prosthesis will tend to sink under repetitive axial loading.
Cement mantle is under considerable shear force.

Design demands

Strong cement mantle with good bond between bone and cement and stem
Proximal collar [Spectron] : to prevent distal sinkage
Tapering of femoral stem [CPT, EXETER] to convert shear stress to compressive load

Prosthesis is also subjected to the bending stress σ :

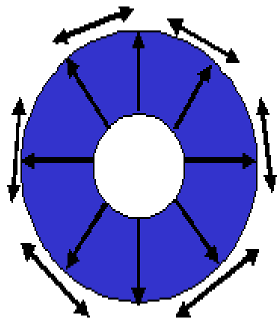
This is dependent on **$\sigma = My/I$ [**M= bending moment, y= distance from neutral axis, I= second moment of area]

A varus stem would increase the distance y and increase σ.

Maximal bending moment occurs proximally and decreases to zero at the distal end.

Bending load also creates radial stress which is greatest at the point of bone-stem contact at the two ends and less in between.

Radial stress generates hoop stress on the outer wall.



Radial and hoop stress

PRACTICAL IMPLICATIONS

The I [second moment arm] of stem being less than that of the femur, the stem is more stressed than the bone.

Stem takes more stress proximally and proximal loosening would result in the distal end being unacceptably stressed.

Too much of stress transfer to the stem could result in stress shielding and eventual periprosthetic bone loss.

Short stems generate large radial stress.

DESIGN DEMANDS

A stem with large enough I [II moment arm] to prevent failure under bending stress

Neutral positioning of the stem (or valgus , but not varus)

A stem with as close as possible matching of rigidity so that there is some proximal load sharing

Good fit of prosthesis in the canal

A long enough stem to reduce radial stress

ACETABULAR LOADING

Acetabulum is under compressive loading. This is mainly taken by the thick subchondral cortical shell. Underlying cancellous bone is soft and is not well suited to taking the load.

Acetabular loading depends on available surface of implant

Commonly used poly acetabular cups undergo creep on loading and can be reduced by a metal backing.

Metal backing increases head-cup contact pressure, which can be reduced by using thick HDP layer.

Design implications

Use of thick layer of Poly
Using Metal backed cup

Controversy in THR :To Collar or not ?

Harris is the main proponent of proximal collar. His arguments in favour of collar are:
Proximal collar allows compressive load transfer from stem to bone
This reduces stress shielding
Reduces shear stress on the cement mantle

However, it is argued
This mode is unable to accommodate creep within the cement mantle
Collar could also work as a pivot around which the tip would move

Ling, on the other hand proposes that
Collarless smooth stem would subside through the cement mantle
This would allow load transfer by radial compression of cement mantle
The stem would subside and eventually attain stability in the mantle

Both are used with good results.

TO CEMENT OR CEMENTLESS ?

A prosthesis , when implanted , needs to be immediately stable. A press fit stem could theoretically achieve this. However, this is difficult in practice.

Press-fit stem might mean having to use a thick stem , which would increase stiffness of the implant and increase stress shielding. This problem is compounded in wide osteoporotic canal – thickened stem-more stress shielding-more bone loss. With tapered cementless, the stress shield does not appear to be a problem. A study ofStress shield revealed that the BMD decreased significantly in Gruen zones 1, 6 and 7 by 3%, 6% and 14% increased significantly in Gruen zones 2, 4 and 5 by 11%, 3% and 11% and there was no net loss of bone

Use of cement or other materials is designed to create a micro inter-lock at the interface to provide strength against different types of loading that the stem is subjected to. Options are:

1. Cemented- by PMMA

2. Uncemented- by porous coating/plasma spray/hydroxyapatite coating

Metallurgy in cemented or cementless:

Stainless steel good for cemented design

Titanium is good for cementless

Cobalt chromium is good for cemented as well as cementless

Cementing of the stem and the cup

It is used as a grout or space filler. This helps to increase stem-bone contact and even out the stress distribution.

If pressurized they would pass onto the trabeculae of cancellous bone and form interlocking bond.

- They are strong but brittle. They have relatively high compressive strength but low tensile and shear strength. If the load is high they will fail.

Alternatives to cement: Bone ingrowth/ongrowth:

Depends on biological fixation created by bone ingrowth into porous surfaces of implants or direct adhesion of bone to implant surfaces.

There are concerns regarding consistency of osseo-integration, femoral component subsidence, porous surface delamination, endosteal bone loss and proximal femoral atrophy.

Prosthetic surfaces are made porous. There are different techniques.

1.Sintering involves porous coating of layers of spherical beads onto substrate by heating.

2.Diffusion bonding involves application of titanium fibre metal pads on titanium alloy substrate by heat and pressure.

3.Plasma spray technique involves gas tungsten-arc welding. This technique spares direct heat to the substrate, allowing retention of mechanical properties and is more desirable of the three

4. Hydroxy apatite coating for stem: 50u [Grit blast or plasma spray] good for stem [Warrick and Ranawat].

In growth [Porous]
Pore ideal size 100-150 u
Substantial strength of integration in 12 wks
Thickness of Hydroxy apatite 50 u
Newer HA coating stems are good. The delamination is not a issue

Ingrowth and ongrowth

- In growth prosthesis — <u>Porous coated</u> Pore size: 50-150u
  50% of prosthesis area
  50um gap between prosthesis and bone
- On growth — <u>Grit blasted</u> Abrasive spray
  Peaks and valleys
  Need more than 50% of prosthesis area

Press fit Vs line to line fit

- <u>Press fit</u>: 1-2 mm undersized
  Hoop stress [bone expands]
  Not uncommon to find: gap in the post op X ray

- <u>Line to line</u>: Bone prepared to the same size
  This needs additional fixation: Porous coating

Ideally the micro-motion of the stem should be 50-100 u [more than 150u may lead to defective osteointegration ie., fibrous layer]

Fully coated stem Vs Partial coated stem in cementless hip

Fully coated	**Proximal Coated**
Covered over 80%	Covered over 40%
Primary/Revision THR	Only primary THR
More stress shield	Less stress shield and less bone loss
Micromotion at the tip: 120um	210um
	Thigh pain is greater & Severe
Superior ingrowth with cortical	Inferior ingrowth proximally
Total area of ingrowth is more = No late loosening	Less =Late loosening observed

Anatomic medullary stem Vs Tappered stem

Recently tapered design is commonly used for following reasons:

No collar and tend to subside and stable

Taper wedge into the femoral canal in a position that provides sufficient rotational stability to ensure bone ingrowth fixation

Excellent axial and rotational stability

Needs minimal reaming and the deleterious effects of extensive reaming are avoided

Thigh pain incidence is less than AML (<5% Vs 10%)

Excellent clinical result

Modular stem

Way to avoid dislocation: offset and neck length, anteversion can be adjusted

No modular: means different size for each hip. More inventory

Templating is difficult in Revision in case of monoblock cementeless stem.

Distal fixation is more important. Does not matter what is done in proximal

S ROM stem is good

Morse taper

Not standarised varies. 2-8®