Biomechanics of Arthroplasty

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Arthroplasty

- **Arthroplasty** (literally "surgical repair of joint") is an operative procedure of orthopedic surgery performed, in which the arthritic or dysfunctional joint surface is replaced with something better or by remodeling or realigning the joint by osteotomy or some other procedure

Introduction

- Total joint replacements
- Increasing demands to understand biomechanics
- Prevention of loads
- Prevention of implant failure
- Younger population
- Long term restoration of function and pain relief

- Several mechanical challenges to achieve these goals
- To meet one design objective , compromise on another design objective.
- For greater rotatory stability--- heavier implants
- Stress shielding

- External forces acting on the joints from outside environment
- Internal forces→ Muscles contraction
- Indeterminate problems in joint peak forces
- Two approaches in analysis of peak forces/ contact forces and muscle forces

- Reduction method= group muscles into functional units
- Optimization method= force distribution so that minimum and maximum forces are optimized

Forces at the Hip Joint

- The peak resultant forces during gait measured with strain-gauged prosthesis have ranged from 1.8 to 4.36 times body weight.
- These forces increase with walking speed
- 2 peaks= one during early stance and 2^{nd} in late stance phase
- Failures not only due to magnitude of forces but also due to cyclic nature of the load

Rotational Moments About the implant

- Out of plane loads may be detrimental to both initial as well as long term implant stability especially uncemented stems
- Excessive implant motion= prevention of bone ingrowths
- Off axis loading frequently observed in stair climbing and rising from the chair

- Walking with decreased range of motion during daily activities may minimize out of plane motions.
- Antero-posterior
- Decreased ROM as adaptive response

Reconstructed joint geometry

- Alterations in joint anatomy impact on hip biomechanics by altering:
  - The contact area
  - The contact force
  - And the strength and moment-generating capacity of the muscles.

- A decreased head neck angle (Varus hip) increases the mechanical advantage of the abductors
- Decreased head-neck angles also improve joint stability through increased congruence by turning the femoral head deeper into the Acetabulum
- Moving the greater Trochanter laterally also increases the mechanical advantage of the abductors.
- Clinically increased abductor/adductor strength has been associated with increased neck length and a more distal greater Trochanter position

- Impact on bending moments on proximal femur
- To decrease bending moments = decreased neck length= compromise on abductor mechanism= increase in joint reaction forces
- joint forces are minimized when the joint center is moved medial, inferior, and anterior

- Pathological conditions strongly influence the potential locations of the hip center
- For instance, osteoarthritis frequently results in the femoral head being displaced laterally, superiorly, and posteriorly

Stem position within the femoral canal

- Valgus stem position better position than Varus position
- Greater peak stresses in the Varus position
- Gait abnormalities

Periprosthetic Bone Loss

- Well documented in cementless/ uncemented femoral stems
- Osteolysis, stress shielding, and generalized limb unloading
- Wear debris= polyethylene→ foreign body reaction→ increased macrophage activity→ increased secretion of intercellular mediators→ stimulation of osteoclasts→ Periprosthetic bone loss

- Unstable and undersized fixation→ more Osteolysis
- Stress shielding→ through implants with greater or equivalent mechanical stiffness
- Bone remodeling does not result in normal mechanical stiffness→ decreased stress distribution

- Limb Disuse
- Abnormal and asymmetric limb use/walking
- The greater the bone loss preoperatively, the less stiff the femur and the more likely stress shielding and associated bone resorption will occur postoperatively

Forces at the knee Joint

- Knee has to depend on surrounding soft tissue for stability
- The peak resultant forces during gait have ranged from 3 to 7 times body weight.
- The magnitude and cyclic nature of the compressive force in the tibiofemoral joint are important considerations in the design of a total knee replacement

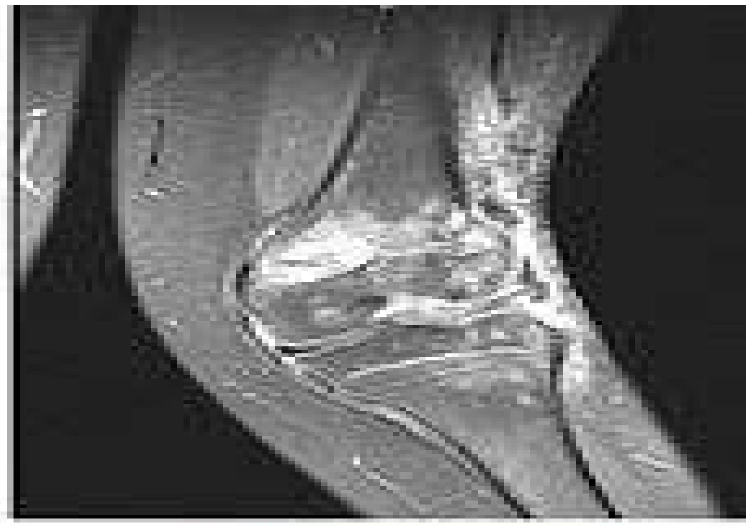
- Failure as a result of implant and interface interaction and cyclic fatigue
- The portion of the tibial plateau that is loaded varies with knee flexion angle
- Smaller the contact area→ larger will be the peak stress
- Tractive rolling of femur on tibia
- Different gait pattern→ different Tractive forces

Medial-Lateral Load Distribution

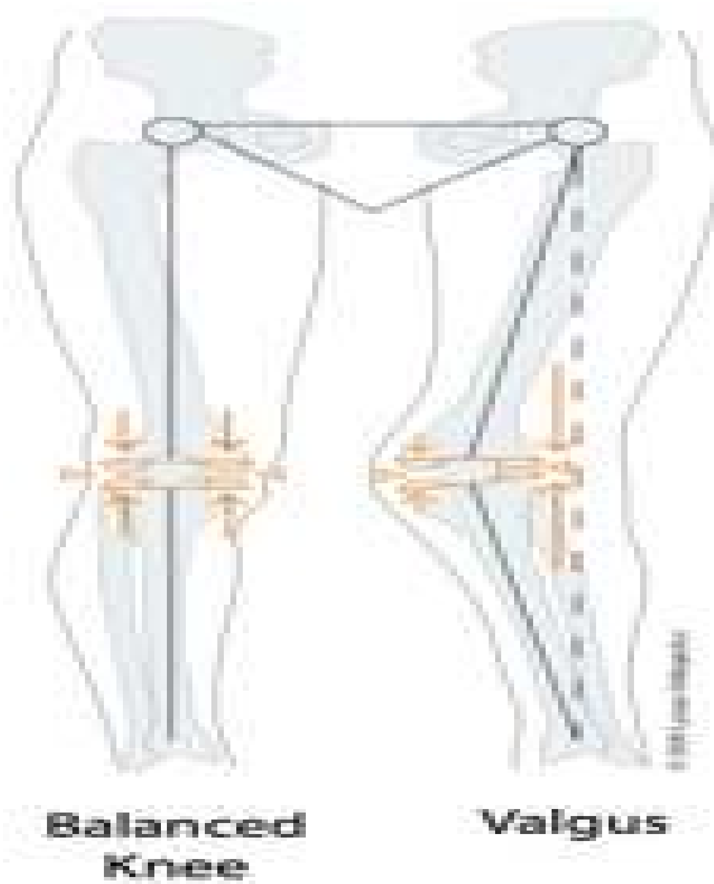
- Tibial component loosening
- Load imbalance between medial and lateral tibial surface
- Early designs were not sufficient to sustain this load difference
- During walking, approximately 70% of the load across the knee joint is normally sustained by the medial compartment of the knee

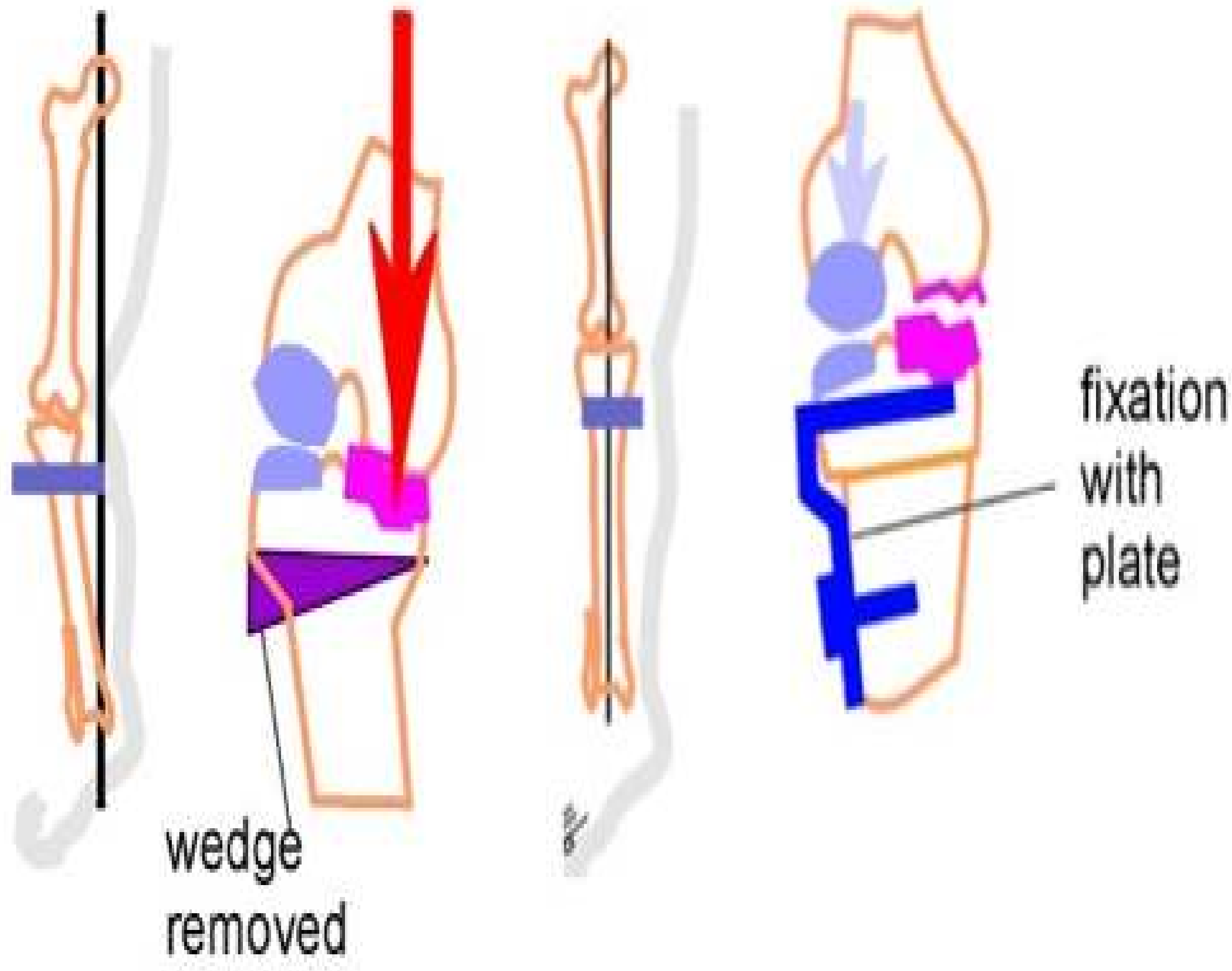
- Adduction moment
- Varus alignment are more likely to have a substantial load imbalance that creates stresses that could eventually lead to tibial component loosening
- Increased wear has been demonstrated in the medial compartment of knees initially in varus preoperatively and in the lateral compartment for those in Valgus preoperatively

Valgus knee

Varus knee


Balanced Knee
Valgus


wedge
removed
fixation
with
plate

- Metal backing of the tibial implant/polyethylene surface
- Modification of surgical approach
- Proper alignment

Patellofemoral joint and loads

- The magnitude of the retro patellar force as well as the contact area on the retro patellar surface varies with knee flexion angle
- Replication of normal Patellofemoral anatomy→ essential
- Elevated joint lines, which affect patella function and patella subluxation, have been correlated with wear patterns

Posterior Cruciate Ligament

- Differing opinions
  - No substantial differences
  - Preoperative range of motion may have a greater influence on the postoperative range of motion than any influence attributable to design differences

- Retention of the posterior Cruciate ligament requires that the joint line be accurately reproduced for the kinematics to remain normal
- Posterior Cruciate ligaments that are too tight ➔ Posterior tracking of the femur on the tibia
  - Limited knee flexion
  - Posterior polyethylene wear.

- Lateral side of the knee can be unweighted during the stance phase of gait and can result in the knee being in a Varus position
- In the absence of a posterior Cruciate ligament, the posteriorly directed shear force is instead sustained by the interfaces of the articulating surfaces

- Variations in the knee kinematics and moments during stair climbing
  - Posterior Cruciate retaining patients have more normal function while ascending stairs than do patients with knees in which the posterior Cruciate ligament is removed
- Increased Soleus activity

Conformity

- The degree of conformity between the femoral component and the tibial component depends on the ratio of the radii of the two components
- Radius of the tibial component increases relative to that of the femoral component, the conformity decreases and the contact stress between the two components increases

- Dished tibial surface and a rounded femoral component
  - A flat geometry has a conformity of one and docs not constrain the rotational or translational movement as required with a posterior Cruciate-retaining design
  - A dished geometry achieves conformity and constraint

Constraint

- Proper soft tissue balance is necessary for a satisfactory outcome
- severe Valgus deformity➔ hinged prosthesis

- Polyethylene damage
  - Thickness
  - Material properties
  - Third body particles
  - Areas of high contact stress
- Difficult to draw definite conclusions

Anterior cruciate ligament

- Total knee replacement→ either totally removed or already absent
- Unicompartmental knee Arthroplasty→ both cruciate ligaments are frequently retained.
- Proprioception loss→ loss of balance→ abnormal flexion extension patterns
- Similar case in injury to the anterior cruciate ligament

- The end