TOTAL KNEE ARTHROPLASTY (TKA)
Anatomy, Biomechanics, and Design

ANATOMY
Size and shape of bones.
Location of soft tissue, nerves, vasculature...

BIOMECHANICS
Kinematics (knee movement).
Kinetics (forces and moments on the knee joint).
Changes in movement due to injury or disease...

DESIGN
Material selection.
Lubrication.
Surface finish.
Manufacturing.
Implantation.
Longevity (wear)

TKA
Femur

• Medial and lateral condyles
  – Convex, asymmetric
  – Medial larger than lateral
Tibia

- Tibial plateau
  - Medial tibial condyle: concave
  - Lateral tibial condyle: flat or convex
- Medial 50% larger than lateral
- Articular cartilage thicker on medial plateau
Menisci

• Two fibrocartilaginous discs on tibial plateaus
• Attached to each other and surrounding soft tissue
• Lateral more mobile
  – Knee kinematics
Function of menisci

• Stability
  – Increases congruency by deepening the tibial plateau
  – Distribute loading and act as “shock absorbers”

• Mobility
  – Decreases friction
  – Must be mobile to avoid injury
Ligaments

- Patellar ligament and patellar tendon
  - Transmit force of quadriceps
- Collateral ligaments
  - Medial-lateral stability
- Cruciate ligaments
  - A-P stability
  - M-L stability
  - Knee rotation
- Many muscles
Function of the patellofemoral joint

- Reduces friction between the quadriceps mechanism and the femur
- Mechanical advantage
  - Increases the quadriceps moment arm
Knee Movement

• Three rotations
  – Sagittal plane: Flexion / Extension
  – Frontal plane: Abduction / Adduction OR Varus / Valgus
  – Transverse plane: Internal Rotation / External Rotation
    ★ Flexion / extension is coupled with internal / external rotation

• Three translations
  – Anterior / Posterior
  – Compression / Distraction
  – Medial / Lateral
Range of motion

- 0° to 140° flexion
  - Range will be dependent on body type
  - Depends on hip position
- A few degrees in abduction/adduction
- 45° external to 30° internal rotation
  - Highly activity and subject-dependent
- Motion is more complex than in the hip
  - Designs that duplicate natural knee motion are more difficult to achieve
  - Longevity of knees is lower than hips
Femoral rollback

- Femoral condyles move posteriorly on tibial plateau with flexion
- Lateral condyle moves farther than medial due to combined rotation and translation.
- Important for impingement concerns
- The observation of femoral rollback is highly dependent on motion analysis methods
  - Especially choice of segment axes.
Total knee arthroplasty

• Treatment for joint disease
• Osteoarthritis
  – Degenerative joint disease that causes deterioration of cartilage between bones
Components

- Femoral component
- Tibial component (tibial base plate)
- Bearing surface
  - Mobile bearing: polyethylene can move relative to the base plate
  - Fixed bearing: polyethylene is locked to the base plate
- Patellar component
TKA design considerations

• Movement (kinematics)
  – Determines range that the implant should be designed for
  – Femoral rollback and screw home mechanism

• Kinetics (joint contact forces)
  – TKA design (computer models, material selection, dimensions)
  – TKA standards (how much force must an implant withstand, and at what positions)
  – TKA testing (real joint simulation)
Wear in Hips (THA) versus Knees (TKA)

**THA**
- Larger contact area than knee
- **Surface** wear mechanisms:
  - Abrasion and adhesion
  - Smaller wear particles

**TKA**
- Contact stresses are an order of magnitude higher than hips
- Alternating tensile and compressive stresses
- **Fatigue** wear mechanisms:
  - Delamination, pitting
  - Larger wear particles
Trade-offs in TKA design geometry

• Highly conforming implants
  – Large contact area $\rightarrow$ Low contact stress
  – Prevents translation $\rightarrow$ Transmits shear stress to fixation interface $\rightarrow$ Implant loosening

• Non-conforming implants
  – Small contact area $\rightarrow$ High contact stress $\rightarrow$ Polyethylene wear $\rightarrow$ Osteolysis $\rightarrow$ Implant loosening
A compromise

• Mobile bearing TKA
  – High conformity (good fit), allows translation (low interface stress)

• Concerns
  – Backside wear
  – Dislocation
To retain the cruciates or not?

- **Cruciate retaining (PCL intact)**
  - Less conformity
  - Allows natural femoral rollback
  - Requires good ligament balancing
  - Proprioception
- **Cruciate substituting (posterior stabilized)**
  - More reliable stability (predictable kinematics)
  - Eliminates possibility of over-tensioning PCL (and the potential for subsequent rupture)
  - More constrained
  - Potential for wear on the tibial spine
  - Possible dislocation
Constraint

Least to Most Constrained

The goal is to use the least-constrained design that will provide a satisfactory result.
Other designs

- High flexion knees
- Revision knees
- Hemi-arthroplasties
- Gender specific
Computer-Assisted Orthopaedic Surgery (CAOS) in Arthroplasty

• Some form of image or model is produced to represent bones
• The bones are tracked throughout surgery.
• The surgical tools are also tracked relative to the bone geometry
• Software:
  – Guides the surgeon for bone cuts and implant alignment/insertion
  – Allows the surgeon to take verification measurements to check that the previous step was correct before moving to the next step.
Hardware

- Infrared markers
  - Active: emit an infrared signal
  - Passive: reflect infrared radiation from a separate source
- Some are fixed to the bone
- Others are attached to tools (drills, jigs, probes,...)
- Electromagnetic systems are also an option
Types of CAOS

- **Pre-operatively imaged**
  - Anatomy is imaged using MRI or CT. Models are made from sequential slices for use in the software
  - Requires a separate imaging session, additional time and cost. Results in patient-specific bone models

- **Peroperatively imaged**
  - Fluoroscopy (low-dose x-ray) used to obtain images at the time of surgery
  - Requires extra time, space, and personnel in the OR. Results in patient-specific bone models

- **Imageless**
  - A generic model is updated with patient measurements during the surgery
  - Less time and cost associated with imaging. Works well with patients who have typical bone structures. Difficulties arise for patients with significant abnormalities/deformities.
Registration

• No matter what type of bone model is used (generic or patient-specific), registration is required.
• Surgeon uses a probe to indicate points or surfaces on the bone that the software will recognize.
• Accuracy of this step is extremely important.
Advantages/Disadvantages of CAOS

- Increased accuracy of implant placement
  - Many complications/revisions are associated with improper implant placement.
- More feedback and verification for the surgeon. Early error detection allows for correction during the surgery.
- Documentation: steps are well-documented with quantitative observations that can be used during follow-up or in research studies.
- Learning curve for surgeons
  - Different software may be required for different procedures, sometimes even different implants
- Significant costs:
  - Hardware, software
  - Additional personnel in the OR
  - Additional space in the OR
  - Operations take longer