Total Hip Arthroplasty:
-component concepts and an overview of normal and abnormal findings

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Inspiration

“Stable alignment. No complications.”
Overview

- Components
  - Materials used
  - Fixation to bone
  - Bearing surfaces

- Post operative radiographic evaluation
  - Normal findings
    - Early
    - Late
  - Pathologic considerations
    - Early
    - Late
Materials

- **Metals**
  - Titanium and titanium alloys (titanium-aluminum-vanadium)—more commonly used today
  - Cobalt-chromium alloys
  - Stainless steel and titanium supporting hardware

- **Cement: space-filler and adhesive**
  - Polymethyl methacrylate (acrylic plastic) mixed with barium

- **Polyethylene: bearing surface lining acetabular component**
  - Ultrahigh molecular weight material also used in bullet-proof vests and lining (“boards”) around hockey rinks.

- **Ceramics: prosthetic femoral heads and acetabular bearing surfaces**
  - Zirconia—more widely known in faux jewelry
  - Alumina—more widely known as ingredient in antacids

Fixation to Bone

- Direct mechanical fixation
  - Internal fixation screws or spikes
- Passive interference fit
  - Tightly fitted components pressed into place (press fit)
- Bone cement
  - Adhesive—gluing component to bone
  - Space-filler contributing to closer interference fit
- Porous ingrowth/ongrowth
  - Remodeling bone attaches directly to component

Types of Replacements

- Bone fixation technique:
  - Cemented
  - Non Cemented
  - Hybrid—combination of cemented and noncemented components

- Bearing surface:
  - Polyethylene
  - Ceramic
  - Metal on metal
  - Combination
Cemented Fixation

- **Benefits**
  - Immediate attachment to bone
    - Early weight bearing
    - Early pain relief
  - Less long term thigh pain

- **Limitations**
  - No integration of bone
  - Some studies report gradual diminution of quality over time

Cementless Fixation

- **Benefits**
  - “Osseointegration”: attachment of lamellar bone to implant

- **Limitations**
  - Integration takes 4-12 wks and may continue up to 3 years
  - Increased reports of thigh pain
  - Stress shielding

Osseointegration: Surface characteristics of an implant

- **Ingrowth:** bone grows inside a porous surface
  - Porous metals
  - Sintered beads—microspheres
  - Fiber mesh coatings

- **Ongrowth:** bone grows onto a roughened surface
  - Grit (abrasive) blasting—may be used as adjunct below mesh or sintered beads
  - Plasma spraying—molten metal powder sprayed on surface

Bearing surfaces

Polyethylene

Metal on metal

Ceramic

Polyethylene

Benefits
- Durable/versatile for most lifestyles
- Long clinical history
- Not toxic

Limitations
- Wear
  - Inflammation/small particle disease
  - Bone loss

Liao, et al, Effects of resin and dose on wear and mechanical properties of cross-linked thermally stabilized UHMWPE, Society for Biomaterials, the 7th World Biomaterials Congress, Sydney, Australia, 2004.
Metal on metal

- **Benefits**
  - Durable/long lasting
  - Low level of wear particles
  - Younger/active patients

- **Limitations**
  - Adverse reaction to metal debris

Ceramic

- **Benefits**
  - Reduced wear
  - Improved lubrication
  - Reduced friction

- **Limitations**
  - More prone to fracture
  - Less forgiving in surgery
  - Chance of squeaking

Postoperative Evaluation

- Normal Findings
  - Early
  - Late
- Pathologic considerations
  - Early
  - Late
Anatomic considerations

Delee and Charnley Zones (acetabular)

Gruen zones (femoral)

Immediate postoperative considerations

- Leg length
- Acetabular inclination/version
- Femoral stem inclination/version
- Femoral tip position
- Material interface/cement mantle
Leg length

- Leg length inequality common after THA
- Up to 27%
- Mean discrepancy 15.9mm
- Up to 10mm thought to be acceptable, but may still be noticeable by patient; may require shoe orthotic
- High source of malpractice

How to measure leg length

- Hips positioned in neutral
- Draw transverse line connecting inferior borders of acetabular teardrops (transverse pelvic axis)
- Lesser trochanter often used as femoral reference point
- Perpendicular line from femoral reference to pelvic reference compared side to side
- Bi-ischial line also described as pelvic reference → rotation of film can make this inaccurate

Woolson ST, et al, Results of a method of leg length equalization for patients undergoing primary total hip replacement, J Arthroplasty, 1999;14:159-64.
Acetabular component position

- Inclination: angle between the acetabular axis (line through medial and lateral cup margins) and the transverse pelvic axis
  - Associated with risk of dislocation
  - Affects range of motion
- McCollum and Grey: safe range 30-50°
- D’Lima: best range of motion: 45-55°

Acetabular component position

- Anteversion: angle between the acetabular axis and the coronal plane
  - Associated with risk of dislocation
  - Affects range of motion
- Rarely calculated by radiologists in day-to-day clinically practice
- Lateral view: exact measurement not possible → degree of angulation affected by pelvic or thigh rotation
- AP view often only view provided
- CT best modality
- Normal range: 5-25°

Anteversion calculation

Anteversion of the Acetabular Cup
Angle of planar anteversion according to the ratios $AB/AC$ and $DE/AC$ (where $AB = X'$ and $DE = Y'$)

Planar anteversion = $13^\circ$

Anteversion calculation from AP view

- Metal-backed cup
  - AC unchanged
  - BD is half of Y’

*In day-to-day clinical practice, inclination angle most commonly assessed.*

Femoral component position

- Goal: stem in neutral position within femoral shaft
- AP view: stem tip should be in center
- Malposition of stem associated with failure
  - Up to 46% failure w/ 16 yr f/u of cemented
  - Correlated with loosening in cementless prostheses

Femoral component position

- Anteversion of neck best assessed on lateral view, but often difficult to evaluate
  - Positioning in elderly or post operative patient
  - Affected by pelvic and thigh rotation
- Femoral anteversion important factor allowing adequate flexion of hip
- Suggested range: 10-15°
- Over-anteversion associated with dislocation
- CT best modality

Material interface (cemented prostheses)

- Assess prosthesis--cement and cement—bone interfaces
  - Thickness
  - Gaps/lucencies
- Deficient cement mantles associated with aseptic loosening and failure of components
- Acetabular mantle 3 mm yield best strain characteristics and reduced loosening risk
  - Sandhu, et al: 78% acetabular components are eccentrically placed with increasing mantle thickness from Delee and Charnley zones I—III (superomedial—inferolateral)
  - Achieving ideal/uniform mantle difficult
- Femoral cement mantle 2-3 mm yield good long term radiographic and clinical outcomes

Material interface (cemented prostheses)

- Assessment of lateral view for cement defects paramount due to common posteriorly angulated prosthesis → thin mantle at posterior tip
- Centralizer may reduce risk of thin mantle around tip

Material interface (cemented prostheses)

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Material interface (noncemented prosthesis)

- Assessing initial fixation more difficult
- Initial postoperative radiographs
  - Alignment evaluation
  - Fixation better assessed with serial follow-up radiographs

Radiographic follow-up of THA

- Periprosthetic lucency
- Component subsidence
- Stress shielding
- Stress loading
Periprosthetic lucency--cemented

- Bone—cement interface a thin fibrous layer forms as response to local necrosis from exothermic cement polymerization—stable by 2 yrs
- Acetabular (Delee-Charnley) zone I: 1-2mm lucency frequent
- Lucency at metal—cement interface initially not uncommon, but should remain stable

**General Rules:**
- Lucency ≤2mm
- Stability over 2 years

-http://www.radiologyassistant.nl/en/431c8258e7ac3
Periprosthetic lucency--noncemented

- Lucencies at metal—bone interface occur typically as combination of bone and fibrous tissue attachment
- Often accompanied by parallel sclerotic line
- Common—80%
- 1-2 mm thickness

**General Rules:**
- Lucency ≤2 mm
- Stability over 2 years

http://www.radiologyassistant.nl/en/431c8258e7ac3
Component subsidence

- Uncemented stems during initial post operative months
  - Beyond 2 years or 10 mm considered abnormal
- Certain cemented stems
  - Exeter: specifically designed to subside into cement mantle
  - 1-2 mm, seen superolaterally

Stress shielding

- Wolf’s Law: Bone will biomechanically remodel and adapt according to the load placed on it.
- THA:
  - Altered forces about hip lead to areas of decreased mechanical load
  - Decreased osteoblastic activity
  - Areas of relative osteopenia—stress shielding
- Generally occurs in first 2 years following surgery
- Implies prosthesis is well fixed
- Long term implications unknown
Stress shielding

- Often seen at proximal—medial femur
  - Calcar resorption/round off
- Also commonly seen at superomedial acetabulum and about the trochanters

- http://www.radiologyassistant.nl/en/431c8258e7ac3
Stress shielding

Stress loading

- Wolf’s Law similarly applies
- Spot welds: small areas of sclerosis originating from endosteal surface and abutting the femoral stem
  - Strong indicators of stability
- Cortical thickening of femoral shaft indicates good fixation

Stress loading—pedestal

- Bridging sclerosis at the tip of the cementless femoral stem
- Unclear significance
  - Can be associated with loosening
  - Careful evaluation and sequential review of follow-up radiographs recommended


Pathologic considerations

- Early postoperative setting
  - Improper placement/alignment
  - Fracture/dislocation
  - Cement migration
  - Limb length discrepancy
  - Nerve palsy: sciatic, femoral, peroneal
  - Hemarthrosis
  - Vascular injury

- Subacute to remote sequelae
  - Fracture/dislocation
  - Loosening/component migration
  - Polyethylene wear
  - Particle disease
  - Infection
  - Adverse reaction to metal debris
  - Heterotopic ossification
Pathologic considerations

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Fracture—prosthesis

- Hardware failure may consist of metal, ceramic, or polyethylene component fracture/displacement
- Failure of supporting hardware (screws)
- May be related to:
  - Trauma
  - Stress shielding
  - Loosening

Fracture—prosthesis

Fractured stem

Fractured ceramic head

Fracture—prosthesis

Broken, frayed, and disintegrating cerclage cables

Side plate placed for periprosthetic fracture, now broken with loss of reduction of femur fracture

http://www.gentili.net/thr/hardware.htm
Fracture—prosthesis

- Phalanged acetabular cup with interval fracture of the medial phalange.
Fracture—prosthesis

Progressive subsidence with subsequent transcortical screw fracture

http://www.radiologyassistant.nl/en/431c8258e7ac3
Fracture—peri-prosthetic

- **Intraoperative**
  - Femoral shaft most common
    - 2º to pounding femoral component in position
    - Rarely displaced
    - Cerclage cables
  - Pelvis rare
  - DDX:
    - Nutrient foramen; compare w/ preop
    - Controlled perforation during surgery/revision

- **Subacute/remote**
  - Femoral shaft most common
    - Greatest torque
  - Osteopenia from inactivity (pre/post op pain/disability) predispose to insufficiency fractures

http://www.gentili.net
Intra-op periprosthetic fracture

http://www.gentili.net/thr/intraopfx.htm
Intra-op periprosthetic fracture

http://www.gentili.net/thr/intraopfx.htm
Intra-op periprosthetic fracture
-Differential diagnosis

- Controlled perforation of the lateral femoral cortex to facilitate removal of old femoral prosthesis

http://www.gentili.net/thr/intraopfx.htm
Intra-op periprosthetic fracture

-Differential diagnosis

- Vascular channel
  - Best seen on lateral, entering femoral cortex distally and traveling proximally
  - “To the elbow I go, from the knee I flee” – direction of channel

http://www.gentili.net/thr/intraopfx.htm
Periprosthetic fracture at follow-up

Commonly about the tip of the stem
Cement migration

 Intrapelvic through defect in acetabulum most common
 Usually asymptomatic
 Rare complications
  • Bowel fistula
  • Neurovascular encasement
  • Bladder wall burn (exothermic cement polymerization)
Cement migration

Medial extrusion through acetabular wall defect

Cement migration

Extravasation through intraoperative fracture at proximal femur

http://www.gentili.net/thr/cement.htm
Loosening/component migration
- General concepts

- Always compare with baseline/post-op radiograph
- Interface assessment
  - >2 mm, loosening
  - 1-2 mm, acceptable if stable (6-12 mon) and asymptomatic
  - <1 mm acceptable
- Acetabular component
  - Delee-Charnley zone I (superolateral) 1-2 mm lucency at cement—bone interface common
  - Delee-Charnley zone III (inferomedial) lucencies more ominous
- Femoral component
  - Gruen zone I (superolateral) 1-2 mm lucency common and not significant
  - >2 mm abnormal
Loosening/component migration - Cemented prosthesis

- 1-2 mm lucencies at cement interfaces common—if stable
  - Prosthesis—cement: minimal motion during cement hardening
  - Cement—bone: fibrous tissue at interface or minimal motion of prosthesis prior to polymerization

- Loosening:
  - Lucency >2 mm
  - Migration of cemented component/change in alignment
  - Progressive widening of radiolucent zone
  - Cement fracture

Loosening/component migration—cemented prosthesis

- Increased lateral inclination
- Lucency in Delee-Charnley zones II and III
- Upward migration/increased tilting
- Fracture of screw
- Increasing lucency zone II and III
Loosening/component migration—cemented prosthesis

Loosening/component migration—cemented prosthesis

- Abnormal lucency at cement—bone interface surrounding entire femoral component

http://www.gentili.net/thr/loosenin.htm
Loosening/component migration—cemented prosthesis

- Abnormal (>2 mm) lucency at prosthesis—cement interface Gruen zone 1 and borderline (2 mm) lucency at zone 7

Loosening/component migration—cemented prosthesis

Cement fracture

Abnormal lucency

http://www.gentili.net/thr/loosenin.htm
Loosening/component migration
-Cementless prosthesis

- Normal findings:
  - Stress shielding (calcar, trochanters)
  - Complete bone-prosthesis lucency (<2 mm) with sclerotic margin
  - Cortical thickening
  - Mild subsidence (<10 mm, nonprogressive)
- Most reliable signs of loosening
  - Progressive subsidence, migration, or tilt
  - May be subtle: serial radiographs and measurements often required
- Probable signs
  - Bone-prosthesis lucency >2 mm
  - Pedestal formation
  - Endosteal scalloping
  - Bead shedding (separation of microspheres on porous coated prostheses)

Loosening/component migration—cementless prosthesis

>2 mm lucency around prosthesis due abnormal motion

Pedestal formation
Loosening/component migration—cementless prosthesis

Loosening/component migration—cementless prosthesis

- Increasing tilt of acetabular component and new acetabular fracture (arrow)
Loosening/component migration—cementless prosthesis

- Bead shedding from the textured coating of femoral component

Loosening/component migration—cementless prosthesis

- Bead shedding from the textured coating of femoral component

Polyethylene wear

- Creep: normal remodeling in a superomedial direction
- Wear: pathologic thinning in superolateral direction from abnormal loading
- Edge loading: highest loads extend beyond contour of cup; alignment critical
- DDX: polyethylene liner dislocation

http://www.radiologyassistant.nl/en/431c8258e7ac3
Polyethylene wear

- Eccentric position of femoral heads in cups

Polyethylene liner dislocation

- Note eccentric position of femoral head in cup and curvilinear density at inferior margin consistent with dislocated liner

http://www.gentili.net/thr/polyethi.htm
Particle disease

- AKA aggressive granulomatosis or osteolysis
- Particulate debris shed into joint fluid from wear of components
  - Typically bearing surfaces (polyethylene, cement, metal)
- Particles transported through small channels (along screws)
- Macrophages and multinucleated giant cells take up particulate and release cytokines initiating cascade reaction leading to osteolysis
- Tend to occur 1-5 yrs post-op, although may occur at any time

http://www.radiologyassistant.nl/en/431c8258e7ac3
http://www.gentili.net/thr/osteolys.htm
Particle disease

- Radiographs
  - Periprosthetic lucencies
    - May be large
    - Not necessarily indicative of instability
  - Smooth endosteal scalloping
  - No secondary bone response
  - Polyethylene wear (secondary finding)
- Relentlessly progressive → loosening, fracture, destruction of bone
- May necessitate revision, even in absence of symptoms, due to danger of fracture or additional loss of bone stock

http://www.radiologyassistant.nl/en/431c8258e7ac3
http://www.gentili.net/thr/osteolys.htm
Particle disease

- Focal osteolysis with endosteal scalloping in Gruen zone 7
- Eccentric position of femoral head in cup—polyethylene wear

http://www.radiologyassistant.nl/en/431c8258e7ac3
Particle disease

- Eccentric position of femoral head in cup—polyethylene wear
- Focal osteolysis with endosteal scalloping in Delee-Charnley zones I—III with granulomatous soft tissue

Infection

- Incidence: 1-2% primary, 3-4% revision
- Radiographic findings:
  - Ill defined bone resorption
  - Sinus tract/gas in soft tissue or joint
  - No sclerotic margin about lucency
- No definitive findings: can mimic loosening and particle disease
- Additional tests:
  - Blood tests
  - Nuclear medicine
  - Joint aspiration often required for diagnosis
Infection

- Irregular periprosthetic bone resorption with periosteal reaction

http://www.radiologyassistant.nl/en/431c8258e7ac3
Infection

- Periprosthetic soft tissue emphysema and gas in joint

http://www.gentili.net/thr/infectio.htm
Abnormal lucency at cement—prosthesis interface
Differential diagnosis

Loosening vs. particle disease vs. infection

- Diffuse lucencies
  - Suggests loosening or infection
- Multifocal lucencies
  - Suggests particle disease or infection
- Polyethylene wear can suggest particle disease
- No specific finding for or against infection
- Normal radiograph does not exclude infection
- Aspiration required to exclude infection

Adverse reaction to metal debris

- Terminology:
  - Metallosis—macroscopic staining of soft tissues associated with abnormal wear
  - Aseptic lymphocytic vasculitis-associated lesions (ALVAL)—histologic appearance occurring with a range of changes from cellular level only to effusion, soft tissue necrosis, and pseudotumor
  - Pseudotumors—periprosthetic mass (solid and/or cystic), can be symptomatic, resemble neoplasms
  - Adverse reaction to metal debris (ARMD)—umbrella term including metallosis, ALVAL, and pseudotumor

*No clear consensus in literature defining boundaries of each term*

Adverse reaction to metal debris

- Appeal of MoM
  - Decreased risk of dislocation due to larger head size
  - Higher levels of activity post-op

- ARMD etiology: deposition of metal wear particles in periprosthetic tissues induces spectrum of necrotic and inflammatory changes
  - 2 general theories:
    - Wear-related cellular cytotoxicity
    - Hypersensitivity

- Incidence: 6-18% at mean of 41 months
  - Higher incidence in women: not clear why, possibly smaller prosthetic size

Adverse reaction to metal debris

- **Local effects:**
  - Metal particles released
  - Macrophages phagocytose particles
  - Particles corrode, release cobalt ions, cell death

- **Systemic effects**
  - Increased metal ion level in blood; grossly elevated when implant loose
  - Solid organ deposition
  - Concerns for long-term effects:
    - Immune mediated
    - Genotoxic
    - ? Teratogenic—insufficient data to date

ARMD—Imaging

- Radiograph evaluation similar to other THA
- Cross sectional: required for imaging adjacent soft tissues/periprosthetic mass
  - MRI: metal artifact reduction sequences (MARS) required
  - US: useful due to absence of metal artifact

ARMD—MRI

- Solid (occasionally cystic) lesions usually low T2 signal—metal deposition
- Gadolinium not required—low vascularity of solid components
- Solid lesions tend to be anterior (psoas muscle)
- Predominately cystic lesions tend to arise from posterior joint space
- Lateral lesions often involve trochanteric bursa

57 yo male left hip MoM THA.
Adverse reaction to metal debris

- Incidence: 6-18% at mean of 41 months\(^1\)
- However...
  - Recent nonpublished (submitted) evidence identifies 69% incidence of pseudotumor in DePuy recall imaging of both asymptomatic and symptomatic patients
  - Presence of symptoms was not correlated with presence or size of pseudotumors
  - Only bone marrow edema and tendon tearing were shown to be significant predictors of pain

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Heterotopic ossification

- Typically around femoral neck and greater trochanter
- Usually asymptomatic
  - Stiffness most common complaint
  - Pain rare
- Up to 39% THA
- May begin 2-3 weeks post-op with possible ankylosis by 12 wks

http://www.radiologyassistant.nl/en/431c8258e7ac3
Heterotopic ossification

- Brooker and Bowerman classification
  - Class 1: Islands of bone in soft tissues
  - Class 2: >1 cm gap in HO between femur and pelvis
  - Class 3: <1 cm gap
  - Class 4: Bony ankylosis

-http://www.radiologyassistant.nl/en/431c8258e7ac3
Heterotopic ossification

Class 3

Class 3-4
Heterotopic ossification

Class 4—complete ankylosis

http://www.gentili.net/Thr/heteroto.htm
"Hip replacement? He was never hip to begin with."
Special thanks

- Eric Chang, MD
References

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