Musculoskeletal Radiology

Radiologic Assessment of Joint Replacement and Bone Graft

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Current Joint Replacements
- 800,000 total hip replacements annually worldwide (200,000 in US)
- 500,000 total knee replacements annually worldwide
- Metal components
- Ultra high molecular weight polyethylene

Future Joint Replacements
- Total hip replacements annually estimated to increase 174% to 572,000 in US by 2030 (compared to 2003)
- Total knee replacements estimated to increase by 673% to 3.48 million in US by 2030 (compared to 2003)

Metallic Components
- Cobalt-chromium-molybdenum alloy
- Cobalt-chromium-tungsten alloy
- Titanium-aluminum-vanadium alloy
- Metal on metal hip resurfacing and total joint replacements

Ultra-High Molecular Weight Polyethylene Component
- Allows articulation of metallic components
- Lowers friction and prolongs wear
- Allows some plastic deformity improving joint congruity
- Radiolucent

Complications of Joint Arthroplasty
- I. Loosening and/or infection
- II. Small particle disease
- III. Dislocation and abnormal alignment
- IV. Fractures and nonunion
- V. Heterotopic bone formation
- VI. Cement extrusion
- VII. Polyethylene liner displacement and metal arthropathy

Loosening and/or Infection
- Most common complication historically
- Difficult to differentiate
- Hip replacement 4%–13%
- Knee arthroplasty 7%–10%
- Approximately 5% failure rate or 95% survival rate at 15 years

Radiographic Signs: Loosening-Infection Cemented Arthroplasty

[Figure 1]
- Cement-bone lucency or cement-metal lucency >2 mm
- Progressive widening of interfaces postop
- Component migration
- Fracture of metal or cement
- Periosteal reaction
- Smooth endosteal scalloping with cement lucency
- Air in soft tissues or joint

Press Fit Joint Arthroplasty
- Ingrowth (beads sintered onto metal surfaces)
- Ongrowth hydroxyapatite (HA)
- Improved longevity
- Bone ingrowth into irregular surface (biologic fixation)
- Technically demanding
- No motion to promote bone ingrowth

Normal Radiographic Appearance

Press Fit Arthroplasty
[Figure 2]
- Resorption of medial femoral cortex
- Thin lucent rim with sclerotic margin about metal (<2 mm)
- Endosteal sclerosis
- Prosthetic subsidence (<10 mm)
- Periosteal reaction and cortical thickening
- Does not progress after 9–12 months postop

Figure 1 A & B
Aseptic loosening of both acetabular and femoral components of a total hip arthroplasty with bone cement (arrows) and cement-metal lucency (arrowheads) that progresses over several years (right image). Cement fracture (open arrow) and lateral migration of the femoral stem (curved arrow) are also apparent.

Figure 2
Resorption of medial femoral cortex, thin lucent rim with sclerotic margin about metal, endosteal sclerosis, prosthetic subsidence, periosteal reaction and cortical thickening do not progress after 9–12 months postop.
Loosening/Infection Radiographic Findings: Press Fit Arthroplasty  

Prominent prosthetic subsidence
Bone destruction
Component migration or motion
Prominent lucent zone about metal (>2 mm)
Increasing number of displaced beads/HA fragments

Metal On Metal Hip Resurfacing Arthroplasty
- Option for younger more active patients
- 10%-35% of primary hip arthroplasties
- Advantages: preserve metadiaphyseal bone stock, reduced dislocation, improved wear properties/biomechanics
- High carbon cobalt-chromium alloys
- Contraindications: large femoral cysts, avascular nerosis, infection
- Similar alignment to other hip arthroplasties with short femoral stem and large femoral head component
- Complications: fractures (femoral neck 1.5%), loosening, hip impingement, iliopsoas tendinopathy, metal hypersensitivity (up to 3%)
- Aseptic lymphocytic vasculitis-associated lesions (ALVAL); Adverse reaction to metal debris (ARMD)
  - Appears as a “pseudotumor” on cross sectional imaging either solid, fluid or mixed

Infection of Total Joint Arthroplasty
- The major long-term complication (0.5%-4%)
  - 33% first 3 months postop
  - 33% 3–12 months postop
  - 33% >12 months postop
- Usually associated with loosening
- Difficult to differentiate from aseptic loosening

Radiographic Signs Most Suspicious for Infection
- Extensive bone destruction
  - 47% sensitive; 96% specific
- Air in soft tissue and/or joint
- Extensive or aggressive periosteal reaction
  - 25% sensitive; 92% specific
- Wide or irregular lucent zone
Radionuclide Evaluation of Total Joint Arthroplasty

- Bone scintigraphy
- Gallium scan
- Indium white blood cells (WBC) scan
- Positron emission tomography (PET)

Bone Scintigraphy

- Normal increased activity postop (6–9 months)
- Increased activity subsequently suspicious for loosening/infection
- Nonspecific
- Overall accuracy (50%–70%)

Gallium (GA-67) Scanning

- In conjunction with bone scan
- Incongruence with increased gallium uptake vs bone scan suspicious for infection
- Not as accurate as bone scan/WBC scan combination

Indium-111 White Blood Cell Scanning

- Increased sensitivity (50%–100%) and specificity (45%–100%) for infection of total joint replacement
- Increased activity at tip of metal components can be normal for up to 2 years postop
- Used in conjunction with bone and bone marrow scans incongruity with more uptake on WBC scan >90% accuracy
- Sensitivity and the ability to correctly localize infection decreases
  - Infection becomes more chronic
  - Anatomic location more central

Arthrography of Joint Arthroplasty

- Purpose
  - Obtain fluid for culture/sensitivity
  - Document intraarticular location
  - Confirm loosening
  - Detect other causes of pain

Knee Arthrography Technique

- Preliminary fluoroscopy and radiographs
- Lateral patellofemoral or anterior intercondylar approach 20-gauge spinal needle
- Aspirate for culture
- If no aspirate inject saline and reaspirate
- Contrast injection with subtraction technique
- Pre- and postexercise radiographs

Arthographic Criteria for Loosening/Infection

- Acetabular component
  - Contrast in bone – cement or metal-cement interface all zones (90%)
  - Contrast in bone – cement or metal-cement interface zones I and II or zones II and III (90%)
  - Contrast in zones I and III with medium or large pseudocapsule bursa (57%)
  - Rim of contrast >2 mm thick any zone (95%)
  - Lymphatic filling (?)

- Femoral component
  - Contrast in cement-bone interface distal to intertrochanteric line (98%)
  - Contrast in bone-metal interface below intertrochanteric line (98%)
  - Contrast at or below mid component-long stemmed prosthesis (98%)

Figure 5

Infection of total knee arthroplasty with early prominent development of lucency and bone destruction (arrows) about both the femoral and tibial components soon following surgery (2 months-previous normal postoperative radiograph not shown).

Figure 6

Digital subtraction arthrogram with contrast in the bone remnant interface of the acetabular component (zone II-arrowhead) and below the intertrochanteric line (arrows) representing aseptic loosening of both components.
Arthrography and Bursa [Figure 7]
- Greater trochanteric (50%)
- Supraacetabular (33%)
- Iliopsoas (17%)
- Can reduce accuracy of arthrography

Dislocation/Abnormal Alignment
Normal Alignment
- Hip:
  - Acetabular angle: about 40 degrees (+/- 10 degrees) – AP view
  - Acetabular anteversion 0–30 degrees – lateral view
- Knee:
  - Tibial plateau component parallel to floor
  - Tibia 5–7 degrees valgus

Abnormal Alignment Predisposing to Subluxation [Figure 10]
- Varus position of knee is unacceptable
- Acetabular angle >50/55 degrees – AP view
- Acetabular anteversion <0 degrees or >30 degrees lateral view
- Exceeding extremes of motion
- Interposed material
- Greater trochanteric separation
- Joint effusion
- Loss of soft tissue support or imbalance (knee)

Small Particle Disease/Osteolysis [Figures 8 & 9]
- Granulomatous pseudotumor/histiocytic reaction/osteolysis (cytokine release)
- Previously unusual arthroplasty late sequelae
- Now may be most common cause of failure
- Large lobulated lucencies and cortical thinning
- Prosthesis loosening (5.3% total hip arthroplasty)

Fracture and Nonunion Associated with Arthroplasty [Figures 11 & 12]
- Bone
- Metal
- Cement
- Polyethylene

Greater Trochanteric Nonunion After Total Hip Arthroplasty [Figure 11]
- Improves exposure at surgery
- Osseous union normally 6–12 weeks
- Nonunion results in lack of abductor support
- Bursitis predisposes to dislocation

Small particle disease as a cause for loosening of femoral and acetabular components of a total hip replacement with multiple largely intracortical areas of radiolucency (arrowheads).
Musculoskeletal Radiology

Joint Replacement and Bone Graft

Cement Extrusion
- Usually clinically insignificant
- Vein or lymphatic
- Rarely nerve, vascular, bowel, or bladder injury

Heterotopic Bone Formation After Total Joint Arthroplasty
- Not infrequent – 3 weeks postop, 2 years to mature; decrease range of motion if severe
- Hip: 15%–76%; knee: 10% anterior to femur
- Predisposing conditions: ankylosing spondylitis (DISH), diffuse idiopathic skeletal hyperostosis, prior occurrence
- Treatment: radiation, steroids, diphosphonates, surgery, Indocin

Brooker Classification Heterotopic Bone
- After hip replacement
  - Class I: small islands of bone
  - Class II: bone projection from acetabulum or femur with >1 cm between osseous surfaces
  - Class III: <1 cm between opposing bridge surfaces
  - Class IV: osseous ankylosis bridging joint

Polyethylene Liner Displacement and Metal Arthropathy
- Allows metal-metal friction
- Inflammation and aseptic synovitis
- Abnormal component position
- Visualize radiolucent polyethylene
- “Metal-line” sign and debris (metallosis)
- Prevented by early recognition

Silicone Arthroplasty
- Complications
  - Fracture
  - Dislocation
  - Infection
  - Silicone arthropathy

Figure 11 A & B
Fracture of greater trochanteric wire mesh on follow-up radiograph (right image) with retraction due to the pull of the abductors (arrow) about the total hip replacement.

Figure 12
Ingrowth total hip replacement with fracture (arrow) at the tip of the femoral component transfixed by cerclage wires. This can occur in up to 7% of patients.

Figure 13
Prominent heterotopic bone formation (arrowheads) about both hips following total hip replacement causing reduced abduction capability on the left leading to resection.

Figure 14 A & B
Displacement of polyethylene liner on follow-up radiograph of total hip replacement (right image). Note widened medial joint space compared to initial postop radiograph (left image), “metal-line” sign (arrowhead), and radiolucent rotated polyethylene liner (†).
Imaging of Bone Grafts

History and Importance:

Bone Graft Procedures
- First performed in 1688
- Second most frequently transplanted tissue
- Vital for orthopedic management

Radiologic Assessment:
Important for Patient Management
- Normal bone graft incorporation
- Abnormal alterations

Imaging Modalities
- Radiographs
- Bone scintigraphy
- Computed tomography (CT)
- Magnetic resonance imaging (MRI)

Bone Grafts Indications
- Delayed and nonunion
- Pseudoarthrosis
- Fill osseous defects or cavities
- Arthrodesis
- Stabilize spinal segments
- Bone stock in arthroplasty
- Restore function in diseased articulations

Classification of Bone Graft by Origin
- Autograft
- Allograft (homograft)
- Xenograft (heterograft)
- Bone graft substitute

Classification of Bone Graft by Structure
- Cancellous
- Cortical
- Combination

Classification of Bone Graft by Technique
- Onlay
- Inlay
- Dowel
- Muscle pedicle
- Strut
- Vascularized
- Clothespin (H)

Radiographic Evaluation of the Donor Site
- Iliac
- Fibula
- Rib
- Distal radius
- Calvarium
- Femoral head
- Tibia
- Greater trochanter
- Posterior spine elements

Figure 15

Figure 16 A & B

Dowel graft placed across a scaphoid nonunion (arrows) with progressive healing at both the bone-grafted site (arrows) and bone graft donor site (arrowheads) on radiographs 3 months apart.

Figure 17

CT of normal iliac bone graft donor site with outer shell of bone retrieved (arrowheads) and no violation of the sacroiliac joint (arrow).

Normal Radiographic Appearance of Donor Site

- Wedge or oval defect
- Irregular margins after surgery
- Initial increase in ill-defined margins
- Subsequent marginal sclerosis
- Complete regeneration

Figure 18

Pictorial representation of onlay (A) and inlay (B) bone graft procedures.
Normal CT Appearance of Graft Donor Site

- Early (up to 1 month): fluid collection, hematoma, air
- Intermediate (1–4 months): fluid collections decrease and replaced by scarlike tissue
- Late (>4 months): scar-like areas become less prominent and cortical thickening predominates

Donor Site Complications

- Pain
- Failure to recognize (radiologists)
- Infection
- Muscle herniation
- Involvement of sacroiliac joint
- Fracture

Normal Bone Graft: Repair/Incorporation

- Cancellous autograft
- Cortical autograft
- Vascularized autograft
- Allograft

Important Terminology: Bone Graft Healing

- Osteoconduction: tissue ingrowth with prominent vascular and mesenchymal components
- Osteoinduction: mesenchymal tissue differentiation into tissue capable of osteogenesis
- Osteogenesis: bone formation

Vascularized Bone Autograft

- Rib
- Iliac
- Fibula

Indications: Vascularized Autograft

- Intercalary defects
- Composite defects
- Mandible reconstruction
- Tumor resection
- Conventional failure
- Congenital pseudarthrosis
### Normal Autograft Healing Cancellous

<table>
<thead>
<tr>
<th>Histology</th>
<th>Radiographic Appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prominent vascular and granulation tissue ingrowth</td>
<td>Graft resorption with ill-defined and irregular margins</td>
</tr>
<tr>
<td>Short initial osteoclastic phase (several weeks)</td>
<td></td>
</tr>
<tr>
<td>Improved osteoinduction and osteogenesis owing to osteoprogenitor cells</td>
<td>Further gradual decrease in graft density and volume (first 1 month) until bone production exceeds resorption</td>
</tr>
<tr>
<td>Improved osteoinduction and osteogenesis owing to osteoprogenitor cells</td>
<td>Gradual hematopoietic tissue ingrowth with graft density increasing to normal, loss of margin between native bone and graft with trabecular continuity and formation of cortex (2–6 months)</td>
</tr>
<tr>
<td>(endosteum and marrow elements)</td>
<td></td>
</tr>
<tr>
<td>Further healing</td>
<td>Structurally weak until incorporation</td>
</tr>
<tr>
<td>Initial increase in strength due to osteoblastic activity</td>
<td></td>
</tr>
</tbody>
</table>

### Normal Autograft Healing: Cortical

<table>
<thead>
<tr>
<th>Histology</th>
<th>Radiographic Appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense bone acts as a barrier with reduced osteocondition</td>
<td>Increased graft osteopenia (6–12 months) most prominent at graft-host junction with irregular, ill-defines margins</td>
</tr>
<tr>
<td>Prolonged osteoclastic activity (12 weeks)</td>
<td></td>
</tr>
<tr>
<td>Reduced osteoinduction and osteogenesis</td>
<td>Density gradually increases to normal (1–2 years) migrating from graft-host junction to mid-graft. Graft remains a combination of necrotic and viable new bone</td>
</tr>
<tr>
<td>Osteonal central canal resorption followed by new bone formation</td>
<td>Transplant cortical and medullary regions remain distinct. As functions returns, graft becomes more dense (55%), stays same density (34%), or become less dense (11%) than normal bone.</td>
</tr>
<tr>
<td>Osteonal central canal resorption followed by new bone formation</td>
<td>Structurally strong; graft hypertrophy seen in 32% of cases (9% atrophy, 58% no change)</td>
</tr>
<tr>
<td>Initially weakened by osteoclastic activity (40%–50% at 12 weeks – 1 year to normal by 2 years</td>
<td></td>
</tr>
</tbody>
</table>

### Vascularized Bone Autograft

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Fibula</th>
<th>Rib</th>
<th>Iliac Crest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length (max)</td>
<td>22–26 cm</td>
<td>30 cm</td>
<td>10 cm</td>
</tr>
<tr>
<td>Shape</td>
<td>Straight</td>
<td>Curved</td>
<td>Slight curve</td>
</tr>
<tr>
<td>Structure</td>
<td>Cortico-cancellous</td>
<td>Membranous</td>
<td>Cortico-cancellous</td>
</tr>
<tr>
<td>Vessels/artery</td>
<td>Peroneal</td>
<td>Posterior intercostal</td>
<td>Deep circumflex-iliac or superficial circumflex iliac</td>
</tr>
<tr>
<td>Vein</td>
<td>2 venae comitantes</td>
<td>1 intercostal</td>
<td>1 vena comitans</td>
</tr>
<tr>
<td>Vascular Stalk</td>
<td>1.0–7.0 cm</td>
<td>3.0–5.0 cm</td>
<td>1.5–5.0 cm</td>
</tr>
</tbody>
</table>
Vascularized Bone Autograft

Advantages
- Graft remains viable
- Promotes healing
- Participates in osteogenesis
- Improved strength

Disadvantages
- Microvascular surgery expertise required
- Increased time for surgery
- Two surgical sites

Autograft Limitations
- Insufficient volume
- Postoperative morbidity risk
- Inability to modify for function

Allograft
- Particulate
- Intercalary
- Osteoarticular

Allograft Healing Depends on the Recognized Immunologic Disparity

Allograft Source and Pretreatment
- Trauma 15–45 years of age
- No history of neoplasm or infection
- No steroids or respirator
- Freeze or freeze-drying

Normal Allograft Healing

Histology
- Inflammatory response-variable degree (8 months or longer): slow vascular ingrowth
- Necrosis
- New bone formation (after 1 month)
- Further healing

Radiographic Appearance
- Bone resorption (prominent at margins) – 7–10 weeks; soft tissue swelling – first 6 months
- Increased allograft density owing to adjacent disuse osteopenia and allograft necrosis (first 6 months): density gradually becomes equivalent to host bone by 2 years
- Periosteal reaction/callus increases (1–1.5 years) progressive loss of lucency between allograft and native bone
- Osseous union 1–1.5 years: allografts successful in this pattern (70%-80%)
Osteoarticular Allograft
- Osteochondral shell
- Half joint
- Whole joint

Osteoarticular Allograft
- Low ratio bone: cartilage requires less pretreatment
- Cartilage immunoprivileged tissue
- Success depends on osseous component

Bone Graft Complications
- Infection (12%–15% for allografts)
- Nonunion or pseudarthrosis (9%–23% for allografts)
- Fracture (10%–16% for allografts)
- Graft resorption
- Joint instability

Infection of Bone Graft
- Persistent tissue swelling
- Periosteal reaction
- Progressive bone destruction
- Lucency about fixation and failure
- Indium WBC scan may add specificity

Infection of Bone Graft
- Autograft
  ➢ Clinical evidence usually present
- Vascularized autograft
  ➢ 5%
- Allograft
  ➢ 5%–13% soft tissue swelling (beyond 6 months postop)
  ➢ Increasing bone resorption (beyond 10 weeks postop)

Nonunion and Pseudarthrosis
- Persistent lucency graft/host junction
- Sclerosis at margins
- Rounded osseous margins
- Fracture or loosening of adjacent fixation
- Stress views helpful

Nonunion and Pseudarthrosis
- Autograft
  ➢ Failure to heal by 12 months
  ➢ 14% in segmental cortical bone grafts
- Vascularized autograft
  ➢ 7% questionable graft viability
  ➢ Bone scan – nonviable if no activity >1 week postop
- Allograft
  ➢ 11% preventable with adequate osseous contact at host/graft junction
  ➢ Treated with regrafting and/or fixation change

Fracture
- Linear lucency through graft
- Callus
- Stress views helpful

Fracture
- Autograft
  ➢ Not infrequent
  ➢ Often after healing with stress (6–8 months)
  ➢ More common in longer grafts
- Vascularized autograft
  ➢ Decreased incidence 3.5% due to improved strength
- Allograft
  ➢ 16.5% most at weak points
  ➢ Affected by pretreatment method

Bone Graft Resorption
- Progressive graft loss
- Graft decreases in size
- Graft decreases in density
- Difficult to distinguish from infection

Bone Graft Resorption
- Autograft
  ➢ Unopposed osteoclastic activity
- Vascularized autograft
  ➢ Same as autograft
- Allograft
  ➢ Acute or chronic rejection
  ➢ Graft replaced by fibrous tissue

Osteochondral Allograft: Joint Instability
- 2.9%–5.5% incidence
- Causes: articular incongruity; lack of innervation and cartilage viability
- Avascular necrosis, neuropathic joint or rejection
- Can be difficult to distinguish from infection or rejection

Figure 21 A, B & C

Allograft infection with progressive lack of osseous bridging (arrowheads) and ultimately fracture of the fixation device (arrow) on 3 sequential radiographs.
**Joint Instability: Radiographic Findings**
- Joint narrowing and sclerosis
- Osteophytes and subchondral cysts
- Fragmentation with debris
- Fracture and migration of fixation
- Weight-bearing views helpful

**Xenograft**
- Supply-demand limitations of other graft
- Calf and ox-bone
- Treated to prevent rejection
- Used as spacer prevents soft tissue ingrowth
- Other graft material in combination

**Bone Graft Substitutes**
- Hydroxyapatite (Ca\(_{10}\) [PO\(_4\)]\(_6\) [(OH)\(_2\)])
- Tricalcium phosphate (Ca\(_3\) [Po\(_4\)]\(_2\))
- Calcium sulphate/Calcium Phosphate synthetic graft (CaSO\(_4\)/CaPO\(_4\))
- Dense or porous ceramics
- Osteoconductive but not osteoinductive

**Calcium Sulphate/Phosphate Synthetic Graft**
- Osteoconductive and osteoinductive
- Radiodense initially like methyl-methacrylate
- Resorbs peripherally to central
- Central lucency probably abnormal
- Complete resorption (89%)
- Mean time to complete incorporation in 5 months
- Radiographs show complete incorporation at 6 months to 1 year in 88%–91% of cases

**Porous Ceramics**
- Goniopora-cancellous bone
- Porites-cortical bone
- Approved human studies 1982
- Initially weak mechanically
- Strength increases after incorporation
- More dense than native bone
- Lucent peripheral band obliterated with ingrowth
- Complications: fractures, implant failure, infection

**Spinal Bone Graft Assessment**
- Causes of failed back surgery syndrome (FBSS)
  - Recurrent disk
  - Arachnoiditis
  - Epidural scar
  - Infection
  - Facet subluxation
  - Spinal stenosis
  - Pseudarthrosis
  - Spine bone autograft: normal healing/incorporation
    - Cervical: 3–4 months
    - Lumbar: by 9 months

**Anterior Vertebral Interbody Fusion**
- Cervical and lumbar spine
- Rib, iliac, or fibular graft
- Initial discrete graft-host junction obliterated

**Radiologic Evaluation: Spine Pseudarthrosis**
- Radiographs
  - Oblique views best; radiolucent defect; motion with bending increase spine curve
- Bone scintigraphy
  - Wide range specificity and sensitivity
  - Norman uptake <6 months postop
  - Abnormal if increased uptake beyond 6 months postop; improved with single-photon emission computed tomography imaging; asymptomatic patients may have focal uptake
- Conventional tomography
  - AP optimal plane (2–5 mm)
  - Best reported method – 96% polydirectional best; limited availability and technically demanding

**Figure 22**
*Pseudoarthrosis of posterolateral lumbar spine graft with horizontal radiolucent clefts (arrows) and surrounding sclerosis on conventional tomography.*
Interbody Fusion Complications

- Nonunion
- Graft fracture
- Extrusion of graft fragments
- Infection

Figure 23 A & B

*Sagittal T1- (left image) and T2-weighted (right image) MR images showing horizontal clefts (arrowheads) in posterolateral lumbar bone graft with high signal on long repetition time image representing 2 sites of pseudoarthrosis.*

References

Joint Replacements


Bone Graft