CHAPTER 49

Primary Knee Arthroplasty

SAMUEL S. WELLMAN MD

MICHAEL P. BOLOGNESI MD

I. Indications and Results

A. Indications
   1. To relieve pain caused by severe knee arthritis
      a. Osteoarthritis
      b. Inflammatory arthritis
      c. Posttraumatic arthritis
   2. Cartilage space loss confirmed on radiographs
   3. Severe pain from gout, pseudogout, and chondrocalcinosis
   4. Severe progressive deformity
   5. Exhaustion of nonsurgical treatment (NSAIDs, injections, activity modification, assistive device for ambulation, low-impact exercise, bracing treatment, and physical therapy)

B. Contraindications
   1. Infection
   2. Incompetent extensor mechanism
   3. Compromised vascularity
   4. Recurvatum deformity secondary to muscular weakness
   5. Local neurologic disruption affecting musculature about the knee
   6. Presence of a painless, well-functioning arthrodesis
   7. Medical conditions precluding participation in a rehabilitation program
   8. Medical conditions that correlate to unacceptable risk profile

C. Results

1. Survival rates for total condylar prostheses range from 91% to 96% at 14- to 15-year follow-up.
2. Newer prosthetic designs must match these results for survival.
    a. The survival rate for cemented posterior cruciate ligament (PCL)–retaining total knee arthroplasty (TKA) ranges from 96% to 97% at 10- to 12-year follow-up.
    b. The survival rate for cemented PCL-substituting TKA is 97% at 10-year follow-up and 94% at 13-year follow-up.
    c. The survival rate for noncemented TKA ranges from 95% to 97% at 10- to 12-year follow-up.

II. Surgical Approach

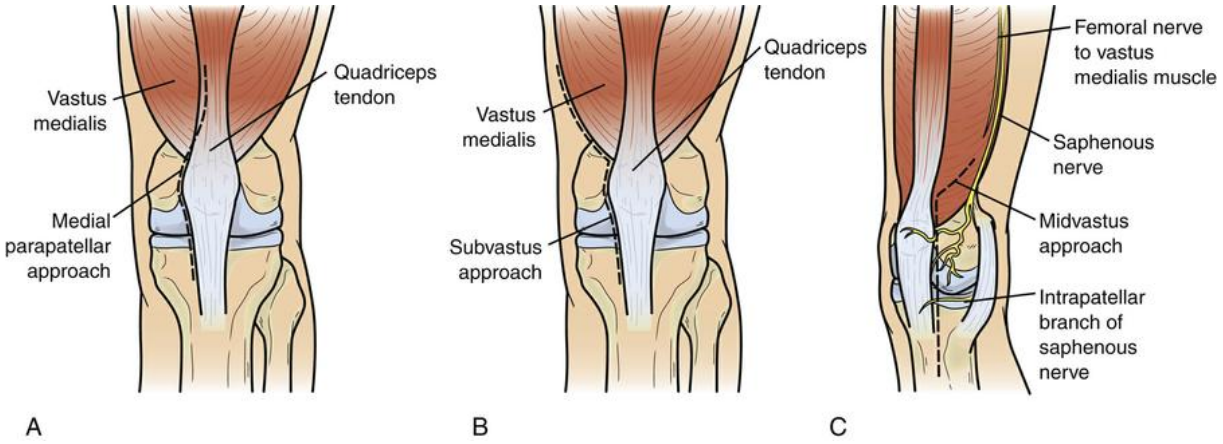


FIGURE 1 Illustrations compare the medial peripatellar (**A**), subvastus (**B**), and midvastus (**C**) approaches.

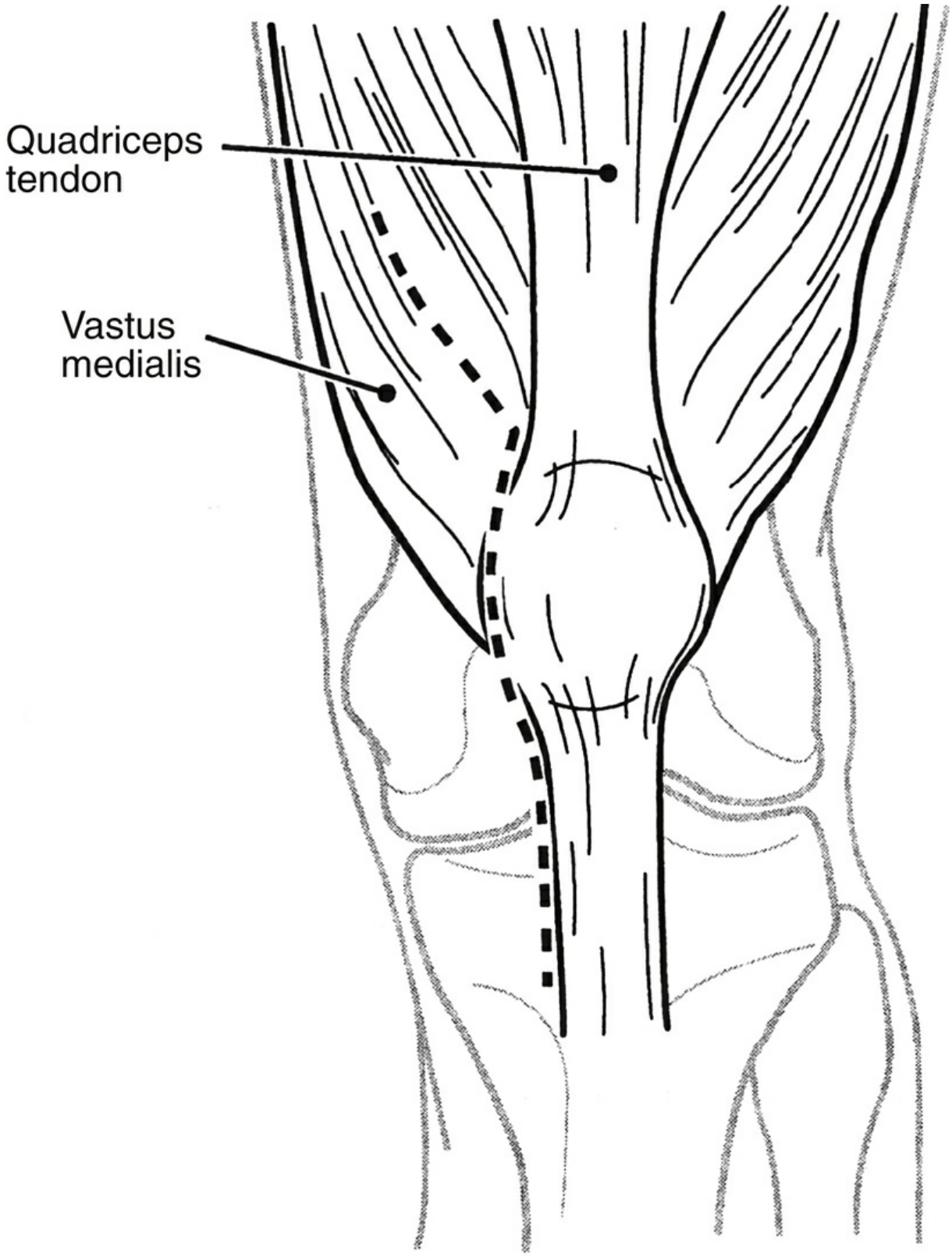


FIGURE 2 Illustration shows the incisions (dashed line) for the midvastus arthrotomy. The dissection is carried between the fibers of the vastus medialis. The quadriceps muscle is not incised.(Reproduced with permission from EnghGA , HoltBP , ParksNL : A midvastus muscle splitting approach for total knee arthroplasty. J Arthroplasty 1997;12[3]:322-331.)

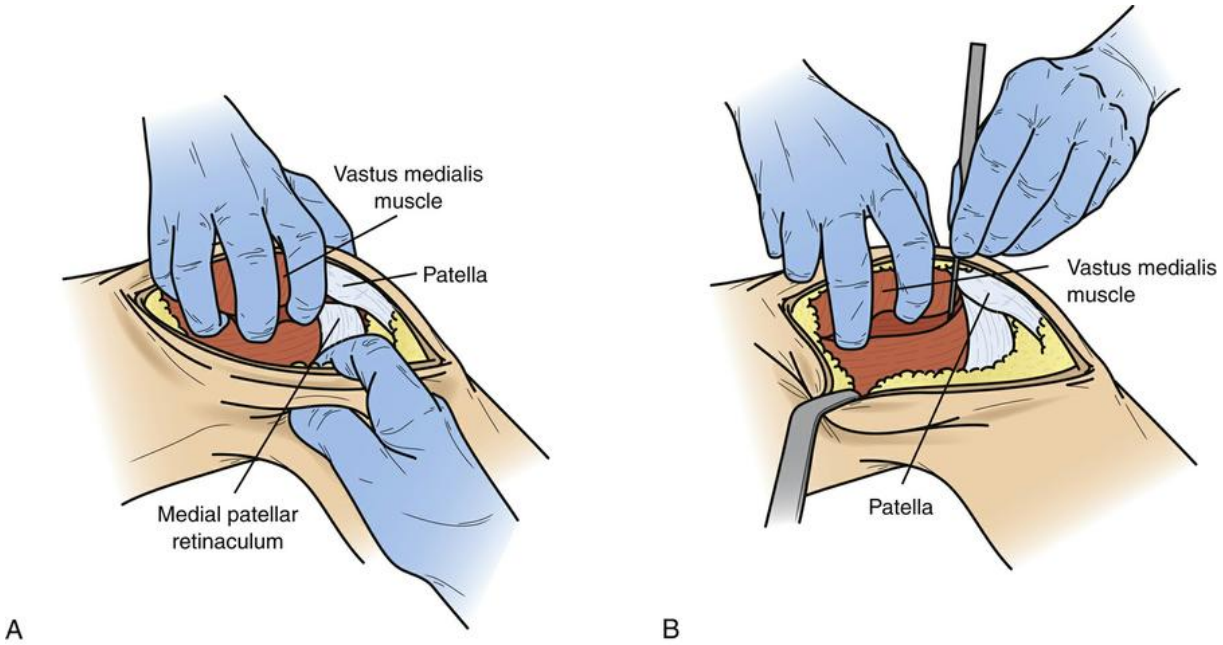


FIGURE 3 Illustrations demonstrate blunt dissection of the vastus medialis off the septum (**A**) and deep arthrotomy (**B**) for subvastus exposure.

TABLE 1
Evolutionary Features of Minimally Invasive Total Knee Arthroplasty

Decreases the skin incision length
Controls the flexion and extension of the leg to gain more exposure
Uses retractors symbiotically to achieve a mobile skin window
Uses quadriceps-sparing approaches
Uses inferior and superior patellar releases to mobilize the patella
Avoids patellar eversion
In situ bone cuts are performed to avoid joint dislocation
Uses downsized instrumentation
Uses bone platforms to complete bone cuts
Possible use of the suspended leg approach to optimize exposure with gravity as an aid

Reproduced from BonuttiPM : Minimally invasive total knee arthroplasty, in BarrackRL , BoothRE , LonnerJH , McCarthyJC , MontMA , RubashHE , eds: *Orthopaedic Knowledge Update*: Hip and Knee Reconstruction, ed 3. Rosemont, IL, American Academy of Orthopaedic Surgeons, 2006, pp 81-92.

A. Superficial
    1. TKA traditionally has been performed through an anterior longitudinal incision.

2. Slight variations on this approach allow different techniques for deeper dissection and instrumentation.

B. Medial parapatellar approach
   1. This is the classic approach used for both primary and revision TKA.
   2. Extensile exposure allows easy patellar retraction and excellent visualization of the entire femoral and tibial anatomy.
   3. Technique—The arthrotomy originates in the medial aspect of the quadriceps tendon and curves along the medial border of the patella down through the anteromedial knee capsule, before finishing just medial to the tibial tubercle (Figure 1). Soft-tissue sleeve release off the proximal medial tibia allows anterior translation and external rotation of the tibia.
   4. Relative contraindication—Previous lateral parapatellar arthrotomy because a new medial arthrotomy risks the remaining blood supply to the patella through the genicular arteries.

C. Midvastus and subvastus approaches
   1. The advantages of each, compared with the medial parapatellar approach, are similar.
      a. The vastus medialis insertion onto the medial border of the quadriceps tendon is not disrupted (Figure 1).
      b. These techniques may allow more rapid restoration of extensor mechanism function (accelerated rehabilitation).
      c. Patellar tracking may be improved, compared with the classic medial parapatellar approach, minimizing the need for lateral retinacular release.
      d. In each approach, the patella is typically subluxated laterally rather than everted.
   2. Relative contraindications
      a. Hypertrophic arthritis with very large osteophytes
      b. Obesity
      c. Preoperative stiffness, especially poor flexion
      d. Previous high tibial osteotomy
      e. Revision TKA
      f. Extremely muscular quadriceps

3. Technique
    a. Midvastus approach—The distal portion of the approach is the same as that used in a standard medial parapatellar approach, but the proximal limb goes medially away from the quadriceps tendon in line with the fibers of the vastus medialis muscle belly (Figure 2).
    b. Subvastus approach—The distal portion of the approach is the same as that used in a standard medial parapatellar approach, but proximally, the entire vastus medialis muscle belly is elevated off the medial intermuscular septum, allowing lateral retraction of the extensor mechanism (Figure 3).

D. Mini-incision approaches
    1. Technique
        a. Several minimally invasive approaches have been described. With these approaches, not only is the quadriceps tendon spared, but the vastus medialis is neither incised nor dissected off the septum.
        b. Some of these techniques do not use an anterior incision, and they require special instrumentation and resection blocks.
        c. These approaches are technically demanding and are associated with substantial learning curves and risks for complications.
        d. The evolutionary features of minimally invasive TKA are described in Table 1
    2. Results
        a. Some results reported suggest that these minimally invasive techniques allow a more rapid recovery.
        b. No long-term data exist to confirm that the early benefits seen with these approaches translate into improved long-term function or survival.

E. Lateral parapatellar approach
    1. Indications—The lateral approach is advocated by some for severe fixed preoperative valgus deformity.
    2. Technique
        a. A laterally biased longitudinal skin incision is used.

b. The arthrotomy originates proximally along the lateral border of the quadriceps tendon and extends distally around the patella to the lateral aspect of the tibial tubercle.
c. This approach, by definition, sections a portion of the iliotibial band, aiding the correction of alignment in valgus knees.
d. The fat pad and the capsule are mobilized to provide an adequate soft-tissue envelope for closure.
e. The extensor mechanism is retracted medially with gradual peel of up to 50% of the lateral portion of the patellar tendon insertion.
f. Arthrotomy closure can be difficult if a large angular correction is attained because the iliotibial band portion of the arthrotomy may not reapproximate.

3. Advantages
   a. The lateral approach avoids the need for a separate lateral release.
   b. It allows a more direct approach to the pathologic lateral anatomy.
   c. It also allows medial displacement of the extensor mechanism, internal rotation of the tibia, and further exposure of the posterolateral corner.
   d. Patellar vascularity is preserved. (The medial blood supply is not violated.)
   e. Optimal tracking is achieved because the retained extensor mechanism has an inherent self-centering tendency.
4. Disadvantages
   a. The lateral approach is technically demanding.
   b. The exposure is less familiar than the medial exposure.
   c. Medial eversion and displacement of the extensor mechanism is more difficult.
5. Relative contraindications
   a. Preoperative stiffness
   b. Patella baja
   c. Obesity

III. Bone Resection

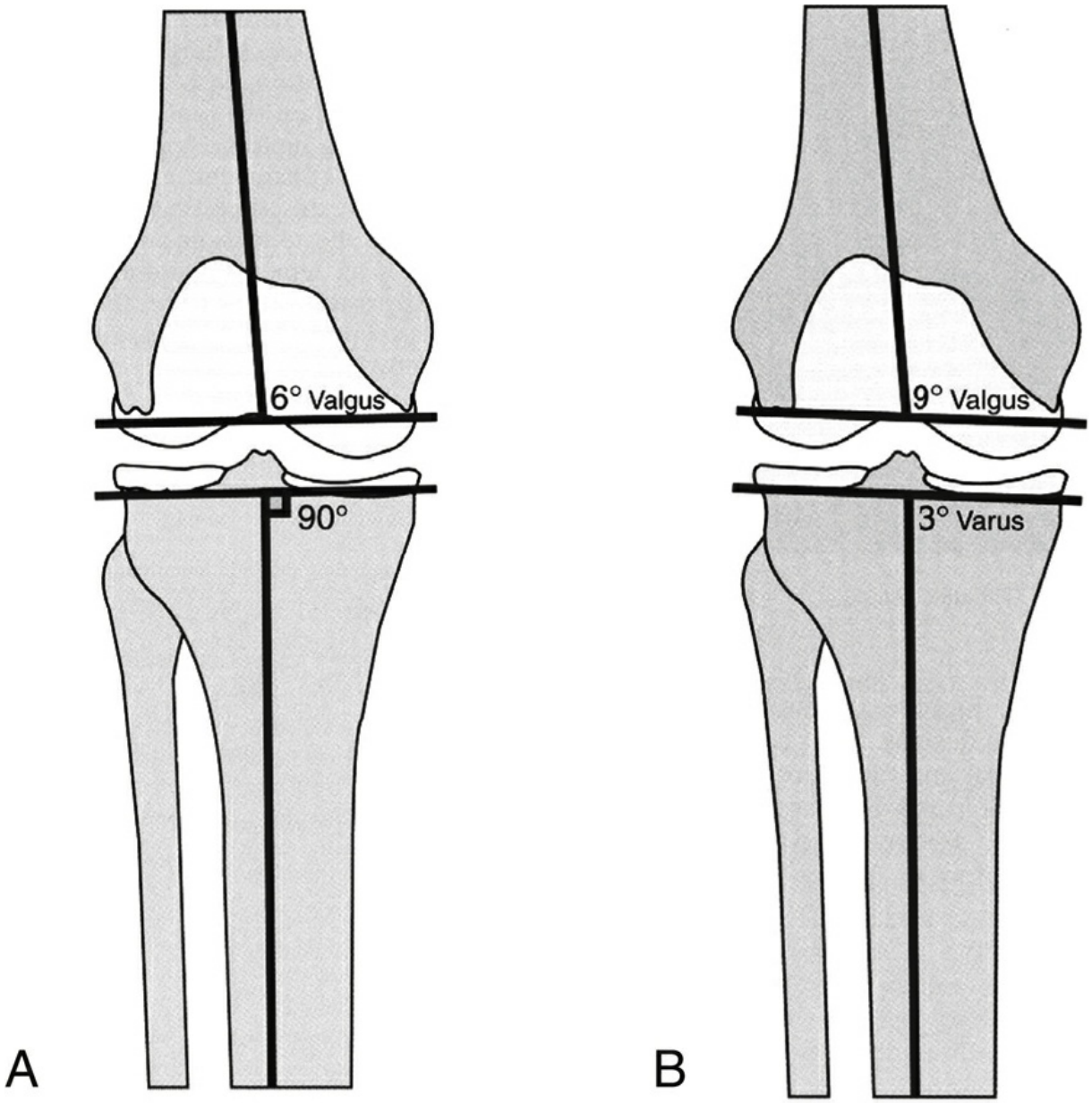


FIGURE 4 Illustrations compare the classic (**A**) and anatomic (**B**) techniques of bone resection for total knee arthroplasty.(Reproduced with permission from Surgical techniques and instrumentation in total knee arthroplasty, in InsallJN , ScottWN , eds: Surgery of the Knee, ed 3. New York, NY, Churchill Livingstone, 2001.)

A. Coronal plane
    1. The standard technique achieves neutral mechanical alignment with a perpendicular tibial cut in the coronal plane. This typically

requires a 5° to 7° distal femur valgus cut compared with the anatomic axis.
    a. This technique theoretically provides even loading across the joint which may afford long-term survivorship advantage.
2. The anatomic technique uses a slightly more valgus femoral cut and a slightly varus tibial cut (Figure 4).
    a. Advantage—This technique more closely replicates the native joint anatomy while maintaining overall neutral alignment.
    b. Disadvantage—Placing the tibial component in a more varus position can increase strain at the bone-cement interface, possibly predisposing to early aseptic loosening.
3. The kinematic technique seeks to recreate coronal and axial positons of the joint line.
    a. Advantage—Potential for more anatomic and fewer ligament release required.
    b. Disadvantage—Unclear impact on long-term survivorship given the wide range of final implant positon.

B. Sagittal plane
1. Femur—This cut is typically perpendicular to the long axis of the femur, or slightly flexed.
2. Tibia—This cut is typically perpendicular to the long axis of the tibia, or sloped posteriorly up to 7° or 8°. The amount of slope depends on the specific design of the knee system and the type of articulation used (less posterior slope with cruciate-substituting designs because resection of the PCL tends to loosen the flexion space).

C. Amount of resection—Enough bone should be resected to allow placement of femoral and tibial components as well as at least the thickness of the thinnest tibial insert. Depending on the knee system, this amount is typically 8 to 10 mm off the most prominent part of the distal femur and 8 to 10 mm off the highest part of the proximal tibia.

IV. Ligament Balancing

TABLE 2

Balancing Flexion and Extension Gaps

Extension	Flexion		
	Loose	**OK**	**Tight**
Loose	Thicker plastic	Augment femur Downsize femur, thicker plastic	Downsize femur, thicker plastic
OK	Resect femur, thicker plastic Release capsule, thicker plastic	No change	Downsize femur Slope tibia
Tight	Resect femur, thicker plastic Release capsule, thicker plastic	Resect femur Release capsule	Thinner plastic (>10 mm) Resect tibia

Adapted with permission from DanielsAU , ToomsRE , HarkessJW , GuytonJL : Arthroplasty, in CanaleST , ed: *Campbell's Operative Orthopaedics*, ed 9. St. Louis, MO, Mosby, 1998, pp 232-295.

A. Overview—The goal of ligament balancing is to achieve equal and symmetric flexion and extension gaps. Flexion gap is typically measured at 90°.

B. Ligament-balancing considerations for various conditions

   1. Varus deformity

      a. Most of the ligament balancing required for a mild varus deformity occurs at the time of exposure.

      b. Subperiosteal medial release or stripping of the medial soft-tissue sleeve off the proximal tibia loosens the medial side. This step involves release of deep medial collateral ligament (MCL) fibers and slight recession of the superficial MCL.

      c. The removal of femoral and tibial osteophytes and the meniscus, with its capsular attachment, further loosens the medial side by shortening the path the MCL takes from the femur to the tibia. The removal of prominent medial osteophytes is an important first step in correcting a varus

deformity and should occur before any further releases are undertaken.

d. Release of the PCL is rarely indicated for a strict varus deformity.
e. For severe, uncorrectable varus, selective division of the MCL or epicondylar osteotomy also has been advocated. Alternatively, the tibial component may be downsized and moved laterally, with removal of the exposed medial tibia, to further loosen the MCL.

2. Valgus deformity
   a. The surgeon must be careful to avoid an overly aggressive medial release during exposure because the medial structures may be attenuated and lax.
   b. Substantial uncorrectable valgus deformities require
      Osteophyte resection
      Lateral capsule release off the tibia
      Iliotibial band release, if tight in extension (a Z-type release, release off the Gerdy tubercle, or pie crusting)
      Popliteus release, if tight laterally in flexion
      Lateral collateral ligament release in extreme cases
      A constrained device should be considered when severe valgus deformity with an incompetent MCL is present.
3. Although the correct order and sequence for anatomic release have been described many times, the overriding concern is to make sure that all tight structures are adequately released to allow for adequate balancing.
4. When correcting combined valgus deformity with flexion contracture, the risk of peroneal nerve palsy is a concern.

C. Flexion contracture
   1. Overview
      a. In patients with fixed flexion contractures, shortened posterior soft tissues prevent full extension.
      b. Most mild flexion contractures are treated by resecting the posterior osteophytes and using appropriate capsular and

soft-tissue releases.

c. Data are mixed as to whether a flexion deformity that persists after implantation can improve with time.

2. Technique
    a. Normal posterior capsular recess is re-created by stripping the adherent capsule proximally off the femur after posterior condylar and posterior osteophyte resection.
    b. Posterior osteophytes are removed to decompress the posterior capsule in extension.
    c. The semimembranosus and gastrocnemius tendons may be released.
3. Additional bone also can be resected from the distal femur in concert with collateral ligament balancing to enlarge the extension gap. Resecting too much bone can raise the joint line and endanger the epicondyles, potentially resulting in poor flexion and instability, respectively.

D. Flexion and extension mismatches
1. Table 2 shows the factors to be considered when balancing flexion and extension gaps. As a rule, if flexion and extension gaps are unequal, alterations need to be made on the femoral side. If the gaps are equal but inappropriate (too tight or too loose), alterations are made on the tibial side.
2. Balancing examples
    a. If tight in extension and flexion, a symmetric gap is present, and more proximal tibia should be cut.
    b. If extension is acceptable and flexion is loose but rectangular, an asymmetric gap is present and too much of the posterior femur was cut, or the posterior tibial slope is excessive. If the slope appears appropriate, the size of the femoral implant should be increased up to the next (anterior to posterior) size, and the posterior gap should be filled with cement or metal augmentation.
    c. If extension is tight and flexion is acceptable, an asymmetric gap is present, and either not enough of the posterior capsule

was released or not enough of the distal femur was cut. Therefore, the posterior capsule should be released, and/or more bone should be removed from the distal femur in 1- to 2-mm increments.

d. If extension is acceptable and flexion is tight, an asymmetric gap is present, and either the tibial bone cut has insufficient posterior slope, or not enough posterior bone was cut off the femoral condyles. Therefore, the size of the femoral implant should be decreased with more posterior condyles cut, the PCL should be recessed, or the posterior slope of the tibia should be assessed and recut if the slope is anterior.

e. If extension is loose and flexion is acceptable, an asymmetric gap is present, and either too much of the distal femur was cut or the anterior-posterior size of the implant is too big. Therefore, distal femoral augmentation should be performed, or a smaller (anterior-posterior) femoral implant should be used, in concert with a thicker polyethylene insert.

V. Polyethylene Insert Options

A. Unconstrained

1. PCL-retaining TKA

a. Advantages

Arguably the best long-term survivorship results

Avoids removal of bone for box cut

Better capability to evaluate postoperative lateral radiographs as a result of absence of box

A well-placed PCL-sparing knee should have roll back from PCL action, allowing good flexion.

b. Disadvantages

Roll back is actually a combination of rolling and sliding (no anterior cruciate ligament), and PCL-sparing knees may have paradoxical motion.

Polyethylene must be flat or only slightly dished to allow roll

back, which may result in increased contact stresses and sliding wear.

There is a potential risk for late PCL failure leading to instability

2. PCL-substituting TKA
    a. Should be used in patients with a previous patellectomy, inflammatory arthritis, a previous PCL injury, or excessive release of the PCL that occurred during surgery

        Substitution of the PCL avoids the technical challenge of balancing the PCL and avoids the risk of late attenuation of the PCL

    b. PS with Post—Polyethylene post and cam between the femoral condyles produces mechanical roll back in flexion.

        Advantage—This design is associated with more predictable flexion than a CR design in some studies.

        Disadvantages

            Impingement between the polyethylene post and the femoral box can result in post breakage or increased polyethylene wear.

            May increase stress on the tibial locking mechanism

            Depending on the design, boxed implants can require extensive bone resection in the region of the box. Presence of box may be associated with patellar clunk syndrome.

    c. Ultracongruent or anterior stabilized—A highly congruent liner with buildup of the anterior lip (allows using a femoral implant without a box or cam) can also be used. The congruency of this articulation minimizes contact stresses. May limit ability to achieve very deep flexion with older designs.

    d. Medial pivot design—Insert with high congruency on the medial side and less minimal congruency lateral. This also allows for use of CR styled femur. This is a newer design with promising results in the studies available thus far.

3. Posterior-stabilized TKA versus cruciate-retaining TKA

a. Numerous studies compare posterior-stabilized TKA with cruciate-retaining TKA.
b. Successful long-term results are achieved with both techniques.
c. Advocates of posterior-stabilized TKA believe that this is a more forgiving and therefore more predictable approach.
d. Surgeons who spare the PCL and use a cruciate-retaining implant highlight the benefit of preserving the anatomy, thereby allowing more idealized kinematic function.

4. Mobile-bearing TKA
    a. Allows motion at the interface between the undersurface of the tibial polyethylene and the top surface of the tibial baseplate
    b. Advocates believe it permits increased range of motion (ROM), lower polyethylene stresses, and a more idealized kinematic knee function.
    c. The increasing conformity of fixed-bearing tibial liner implants reduces polyethylene stress but increases stress at the tibial fixation interfaces.
    d. A theoretical advantage of mobile-bearing TKA is that the articular surface of the implant can be congruent over the entire ROM without increasing constraint.
        This results in lower contact stresses because of the increased contact area.
        Some authors believe lower contact stresses translate into a lower incidence of osteolysis.
    e. No data show whether these apparent advantages regarding contact stresses actually translate into decreased wear and osteolysis in vivo.
5. High-flexion TKA
    a. Numerous vendors have created implants designed for higher flexion.
    b. Modifications in femoral implant design as well as tibial articular geometry have allowed larger theoretical total arcs of motion (135° to 155°).
    c. Studies to date have not always substantiated a notable increase

in postoperative flexion

6. Postoperative motion—Regardless of TKA implant design, preoperative ROM remains the most consistent predictor of postoperative ROM. It is unlikely that implant design modifications can change this association.

B. Constrained nonhinged
   1. Advantages—Increased varus-valgus and rotational support afforded by a tight fit between the large polyethylene post and deeper femoral box; appropriate for revision TKA or primary TKA with severe preoperative deformity
   2. Disadvantages
      a. Increased component-bone interface stress, which can potentially increase the rates of aseptic loosening. Therefore, stem augmentation of implants is advised.
      b. The increased stress on the polyethylene post from a tight fit can increase polyethylene wear generation. Many such components include a metal reinforcing pin within the polyethylene post.

C. Rotating hinge
   1. Advantage—Complete varus-valgus and anterior-posterior constraint for knees with absent ligamentous stability
   2. Disadvantages
      a. Potentially restricted ROM
      b. High degree of bone-cement interface stress
      c. Stems required

D. Cross-linked versus standard polyethylene
   1. Long-term data are available only for standard polyethylene.
   2. Delamination, pitting, oxidation, and osteolysis are the long-term problems associated with standard polyethylene.
   3. Cross-linked polyethylene has been introduced in TKA in the past several years.
      a. Some manufacturers use the same polyethylene formulation for TKA as that used for total hip arthroplasty (THA), but others ◎have specific cross-linking levels and polyethylene treatment

strategies for TKA polyethylene.

b. Wear simulator data are promising for cross-linked polyethylene, but concerns remain about novel failure modes, compared with standard polyethylene, including polyethylene fracture, especially in posterior-stabilized knees.

c. Cross-linked patellar buttons also are available but appear to have a higher risk of polyethylene fracture compared with standard buttons.

VI. Fixation

A. Overview—Data from 10-year follow-up studies support using both cemented and noncemented techniques.

B. Cemented fixation

1. Cemented fixation is the benchmark for TKA across all indications.
2. The optimization of cementing techniques has produced reliable and durable fixation for all three components (patella, femur, and tibia).
3. Meticulous technique is critical.
    a. The cement is prepared with vacuum suction or centrifugation to minimize voids within the cement that can weaken the cement.
    b. Cancellous bone is cleaned with pulsatile lavage and then dried at the time of implantation. Drying can be augmented with intraosseous suction or negative-pressure intrusion into the proximal tibia.
    c. The ideal amount of cement penetration into bone is approximately 3 mm. Bone cement is not adhesive; instead, it acts as grout. The bond to bone depends on interdigitation.
4. Standard bone cement versus premixed antibiotic cement
    a. Commercially mixed antibiotic cement that contains gentamycin or tobramycin is available. The total antibiotic load is limited by the potential negative impact on the mechanical properties of the cement.

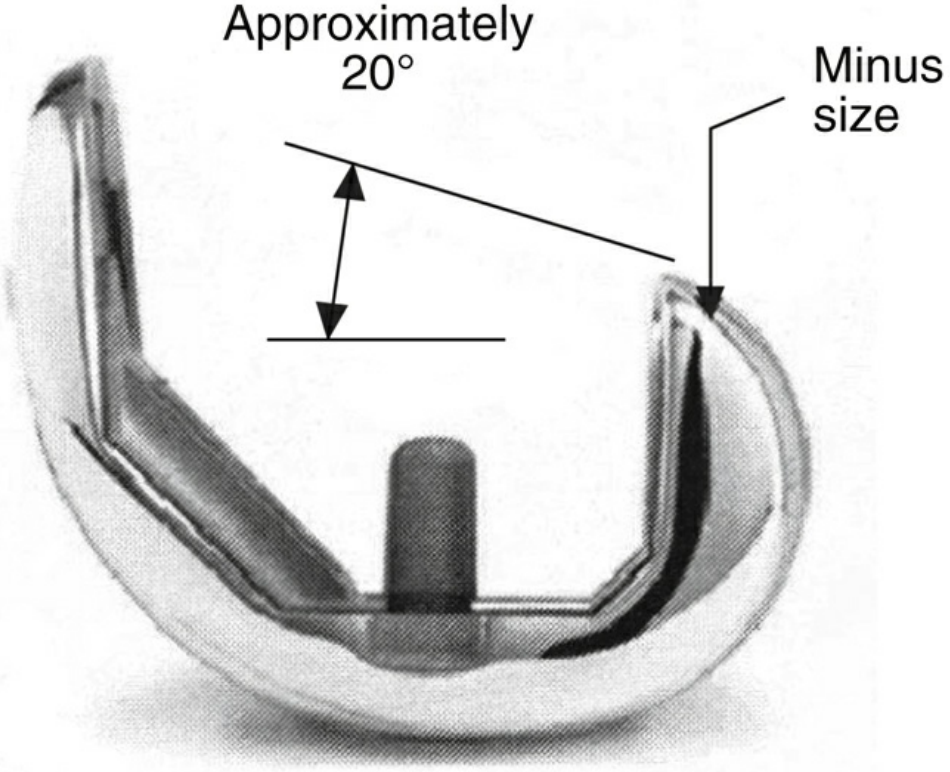
b. Some European registry data suggest a slight reduction in the infection rate with antibiotic cement, but the overall data are equivocal.
c. The cost of commercially mixed antibiotic cement is substantially higher than nonantibiotic cement.

5. Complications—Early to late-term aseptic loosening can occur. Cement mantles that endure longer than 10 years tend to be lifetime bonds, assuming that no osteolysis occurs. Aseptic loosening is more common in heavy and high-demand patients.

C. Noncemented fixation

1. Noncemented fixation has not had the success in TKA as in THA, despite many attempts to perfect the technique.
2. Implant designs have varied in both ingrowth surfaces and the types and extent of adjunctive fixation.
3. Complications
   a. The biggest challenges involve the patellar and tibial components, with pain and a positive bone scan with lucency (assume tibial fibrous union) reported.
   b. Femoral fixation has been reliable across different designs.
   c. The most common late complication is osteolysis.
4. When the following key requirements are met, the survival of noncemented TKA rivals the long-term success seen in the cemented technique.
   a. Optimal porous coating
   b. Tibial stem design that enhances stability
   c. Meticulous surgical technique
   d. Irrigation of bone cuts to avoid thermal necrosis
   e. Some type of adjunctive (peripheral) fixation (screws or pegs)
5. Improvement in fixation technology will likely achieve more predictable outcomes for noncemented TKA. The potential advantage of this technique is the establishment of a lifetime biologic bond between the bone and the components, allowing higher activity levels without loosening.

VII. Patellofemoral Joint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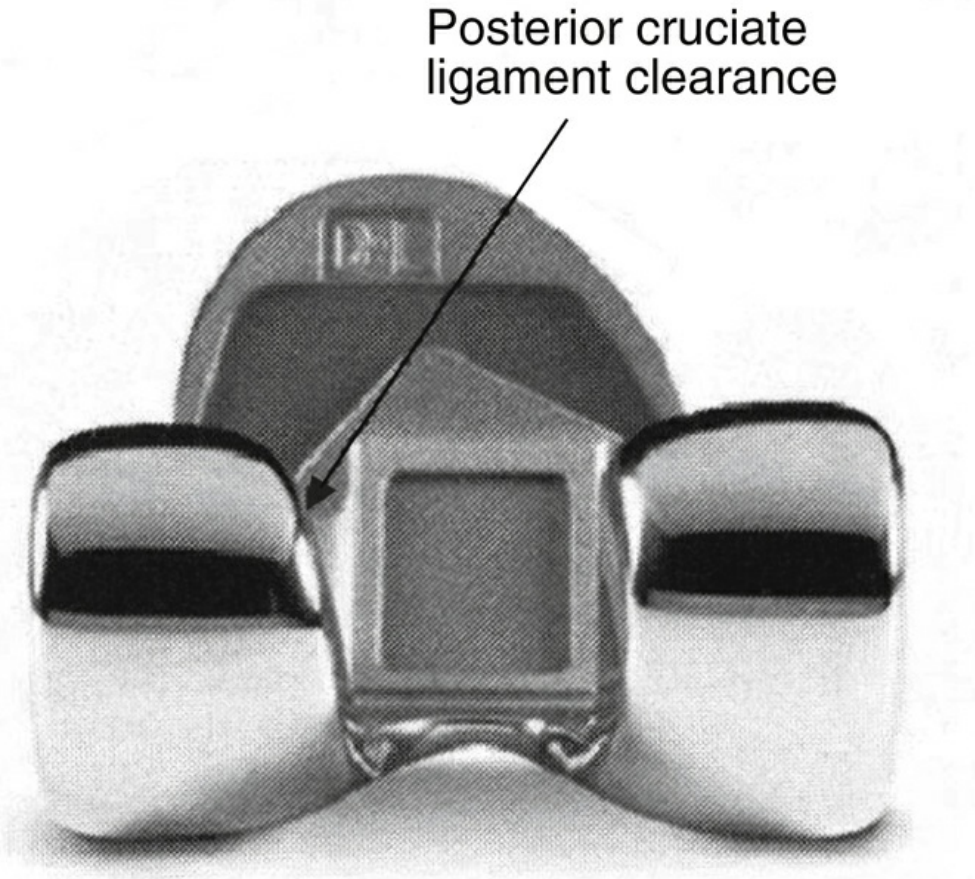
Posterior cruciate
ligament clearance

FIGURE 5 Photographs show prosthesis design modifications that permit high flexion. The minus size, between the standard size and the size below, allows fine tuning of soft-tissue balancing.(Reproduced from WalkerPS : Total knee implant design, in BarrackRL , BoothRE , LonnerJH , McCarthyJC , MontMA , RubashHE , eds: Orthopaedic Knowledge Update: Hip and Knee Reconstruction, ed 3. Rosemont, IL, American Academy of Orthopaedic Surgeons, 2006, pp 31-42.)

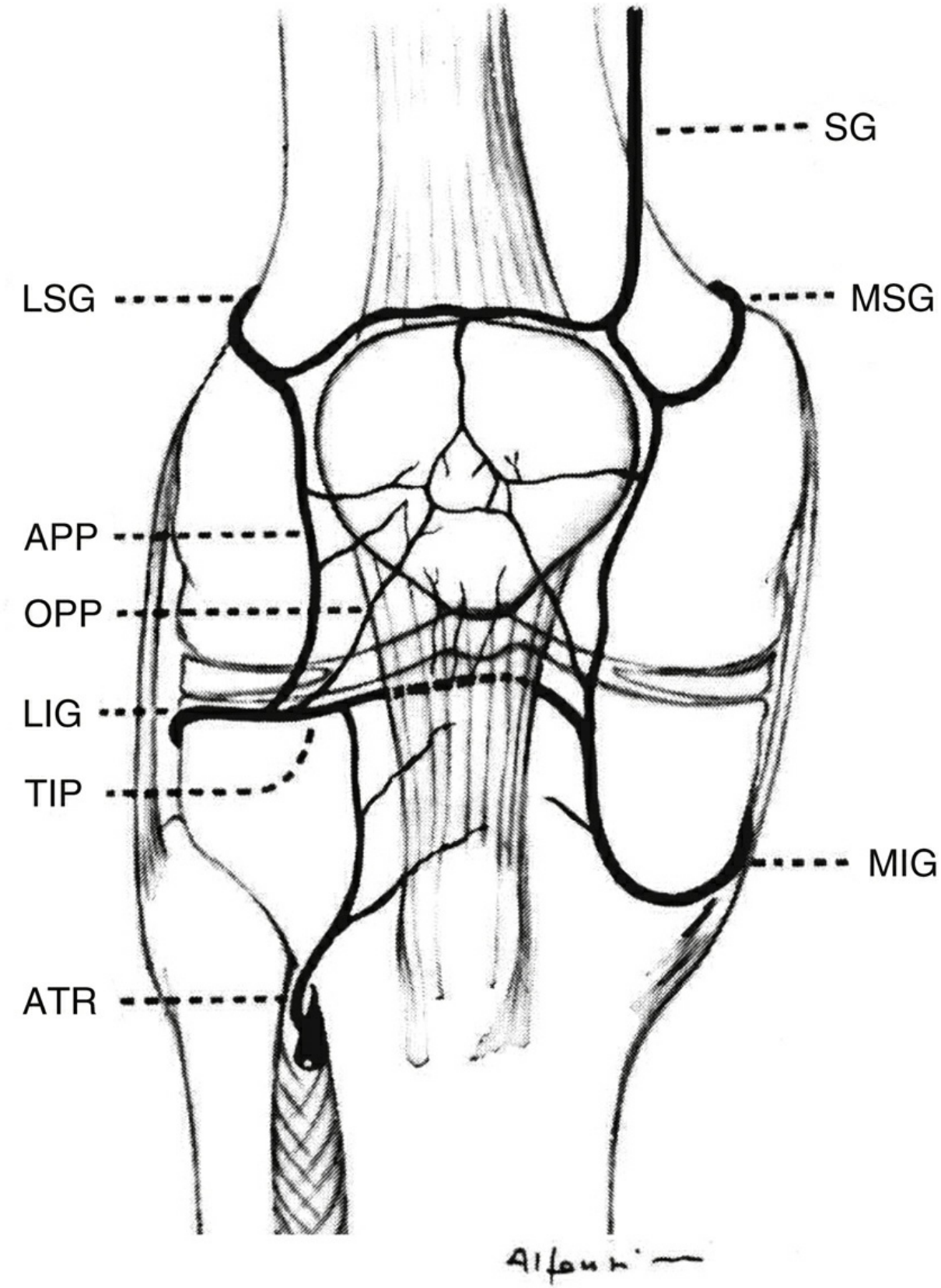

FIGURE 6 Schematic representation of the patellar blood supply. APP = ascending parapatellar artery, ATR = anterior tibial recurrent artery, LIG = lateral inferior genicular artery, LSG = lateral superior genicular artery, MIG = medial inferior genicular artery, MSG = medial superior genicular artery, OPP = oblique prepatellar artery, SG = supreme genicular artery,

TIP = transverse infrapatellar artery.(Reproduced with permission from HofmannAA , PlasterRL , MurdockLE : Subvastus [Southern] approach for primary total knee arthroplasty. Clin Orthop Relat Res 1991;269:70-77.)

A. Resurfacing versus not resurfacing
    1. Data support both resurfacing and not resurfacing the patella at the time of TKA.
    2. Some data suggest an increased incidence of anterior knee pain postoperatively when the patella is not resurfaced.
    3. Data conclusively show that the survival of some patellar components is inferior to the survival of the tibial and femoral components.
    4. Poor results have been attributed to several factors.
        a. Inferior prosthetic design (metal-backed patellar components)
            High failure rate
            Poor ingrowth
            Peg failure
            Dissociation of polyethylene
            Component fracture
        b. Suboptimal surgical technique
            Asymmetric resection
            Overstuffing the patellofemoral joint
            Excessive patellar resection
            Poor patellar tracking resulting from femoral and/or tibial malrotation
    5. Complication rates have been reduced to 0 to 4% with improved technique that focuses on several factors.
        a. Equal facet thickness
        b. Maintaining the native patellar height
        c. Good patellofemoral tracking
        d. Exercising care to maintain the vascular supply to the patella
    6. Patients with the following attributes can be considered for an unresurfaced patella
        a. Young age

b. Normal weight
c. Noninflammatory arthritis
d. Well-preserved patellar cartilage
e. Ideal patellar tracking
f. Limited anterior knee pain preoperatively

7. It is critical to use a femoral implant with a design that accommodates the native patella.

B. Patellar blood supply
1. The patella is a sesamoid bone.
2. The patella has an extraosseous blood supply and an intraosseous blood supply.
a. The extraosseous blood supply consists of an anastomotic ring that encircles the patella itself. This ring receives blood from all the geniculates (Figure 6).
b. The intraosseous blood supply is damaged during resurfacing, theoretically leaving only the superior lateral genicular artery after surgery.

C. Patellectomy
1. Patellectomy has been used to treat severe isolated patellofemoral arthritis.
2. Experimental data suggest a 25% to 60% reduction in extension power following patellar resection.
a. A substantial increase in tibiofemoral joint reaction forces also may occur.
b. A substantial increase in tibiofemoral joint reaction forces may explain the high incidence of arthrosis in the medial and lateral compartments following patellectomy.
3. If TKA is performed after a patellectomy, a posterior-stabilized component should be used.
4. The results of TKA in patients who also undergo patellectomy have generally been less successful compared with patients in whom the patella is not compromised.

D. Rotational malalignment
1. Patellar maltracking must be avoided when performing TKA.

2. The most common technical complications in TKA involve abnormal patellar tracking.
3. Surgeons must avoid creating an increased Q angle (the angle formed by the intersection of the extensor mechanism axis above the patella with the axis of the patellar tendon) to avoid increased lateral patellar subluxation forces.
4. Internal rotation of the femoral implant should be avoided because it causes lateral patellar tilt and a net increase in the Q angle.
5. The femoral implant should be placed in a mean of 3° of external rotation to the neutral axis to maintain a symmetric flexion gap.
    a. The line perpendicular to the anterior-posterior axis is the neutral rotational axis.
    b. The epicondylar axis is usually slightly externally rotated to the neutral axis; the component should be placed parallel to the transepicondylar axis.
6. The femoral implant should be biased to a lateralized position because medialization places the trochlear groove in a medial position and increases the Q angle.
7. The midpoint of the tibial component should align over the medial third of the tibial tubercle, and care should be taken to avoid an internally rotated position and err toward external rotation.
8. Internal rotation of the tibial component results in external rotation of the tubercle and increases the Q angle.
9. The patellar button should be biased medially and superiorly on the undersurface of the patella bone.
10. Rotational malalignment of the femoral and/or tibial component, and the resultant patellar maltracking, is a substantial source of persistent pain, poor ROM, and patient dissatisfaction following TKA.

VIII. Complications of TKA

TABLE 3

Factors Affecting Neurovascular Injury Following Total Knee Arthroplasty

Severe valgus and flexion deformities
Preoperative neuropathy
Tourniquet use longer than 120 min
Postoperative bleeding complications
Epidural anesthesia

Reproduced from ScuderiGR , TrousdaleRT : Complications after total knee arthroplasty, in BarrackRL , BoothRE , LonnerH , McCarthyJC , MontMA , RubashHE , eds: *Orthopaedic Knowledge Update*: Hip and Knee Reconstruction, ed 3. Rosemont, IL, American Academy of Orthopaedic Surgeons, 2006, pp 147-156.

A. Instability

1. Symptomatic instability reportedly occurs in 1% to 2% of patients undergoing TKA, but the true incidence likely is higher.
2. Instability accounts for 10% to 20% of all TKA revisions.
3. Instability occurs in the mediolateral plane (axial instability) and the anterior-posterior plane (flexion instability).
4. Several factors may contribute to instability.
    a. Ligament imbalance
    b. Malalignment, inaccurate sizing, or failure of component
    c. Implant design
    d. Mediolateral instability (symmetric or asymmetric)
    e. Bone loss from overresection of the femur
    f. Bone loss from femoral or tibial component loosening
    g. Soft-tissue laxity of the collateral ligaments
    h. Connective tissue disorders (eg, rheumatoid arthritis, Ehlers-Danlos syndrome)
    i. Collateral ligament imbalance (eg, underrelease, overrelease, traumatic disruption)
5. Axial instability
    a. If symmetric (flexion and extension), a thicker tibial liner can be used.
    b. If asymmetric, then component revision is required.
6. Flexion instability occurs when the flexion gap is larger than the extension gap.
    a. It can occur with anteriorization and downsizing of the femoral implant.

b. It can result in posterior dislocation (0.15% of TKAs with a posterior-stabilized prosthesis) (Figure 5).
c. Instability also can occur with PCL-retaining designs.
d. PCL-retaining TKAs with instability should be revised to posterior-stabilized TKAs.
e. Posterior-stabilized TKAs need to be revised if dislocation is recurrent; the results are variable.

B. Heterotopic ossification
1. Heterotopic ossification can occur following TKA.
2. Its incidence is lower than that seen following THA.
3. It can result from periosteal stripping.
a. Some surgeons have suggested that excessive dissection of the anterior femur can result in the development of heterotopic ossification just proximal to the anterior flange of the femoral implant.
b. This may have implications for ROM if scarring of the extensor mechanism occurs as a secondary result.
4. It also is critical to be aware that periprosthetic heterotopic ossification may indicate indolent infection.

C. Vascular injury
1. The incidence of vascular injury following TKA is quite low.
2. A vascular examination should be performed and documented before the procedure.
3. It is critical to avoid sharp dissection in the posterior compartment of the knee.
4. Posterior retractor placement also must be performed carefully and should be biased to a medial position away from the popliteal artery; this artery has been shown to lie 9 mm posterior to the posterior cortex of the tibia at 90° of flexion and slightly lateral to midline.
5. If arterial injury is suspected, the tourniquet must be dropped to check the artery.
6. Popliteal artery injury can result in acute ischemia, compartment syndrome, and potential amputation.

D. Nerve palsy

1. The incidence of nerve injury following TKA has been reported to be 0.3%.
2. In patients with severe valgus deformities, the rate of peroneal nerve injury increases to 3% to 4%. Patients with both a valgus deformity and a flexion contracture are at highest risk for peroneal nerve palsy.
3. Severe flexion contracture of greater than 60° occurs in 8% to 10% of patients.
4. The risk factors that appear to increase the incidence of nerve palsy are listed in Table 3.
5. If peroneal nerve palsy is suspected following TKA, the patient's leg should be immediately flexed, and all compression dressings should be removed.
6. Initial management should include using an ankle-foot orthosis.
7. If dorsiflexion does not recover, a late decompression of the nerve or muscle transfer can be considered, pending full neurologic evaluation.

E. Wound complications

1. Systemic factors
    a. Type II diabetes mellitus
    b. Vascular disease
    c. Rheumatoid arthritis
    d. Medications
    e. Tobacco use
    f. Nutritional status
    g. Albumin less than 3.5 g/dL
    h. Total lymphocyte count less than 1,500/µL
    i. Perioperative anemia
    j. Obesity
2. Local factors
    a. Previous incisions

        The most lateral acceptable incision should be used.

        Skin bridges larger than 5 to 6 cm should be used.

Care should be taken to avoid crossing old incisions at angles less than 60°.

b. Deformity
c. Skin adhesions secondary to surgery or trauma can affect local blood supply.

3. Technique
   a. Length of incision—Short incisions may involve substantial skin traction.
   b. Large subcutaneous skin flaps may be associated with skin compromise.
   c. Preservation of the subcutaneous fat layer preserves skin vascularity.
   d. Completion of arthroplasty in a reasonable time
   e. Minimizing tourniquet time
4. Several postoperative factors can help prevent wound complications.
   a. Hematoma should be avoided.
   b. Consider limiting flexion in the first 3 to 4 days should be avoided in patients with high-risk incisions.
   c. Nasal oxygen should be used in at-risk patients the first 24 to 48 hours postoperatively.
   d. Tissue expanders may be used preoperatively to facilitate closure in cases with poor or missing tissue.
   e. When wounds drain longer than 5 to 7 days, aggressive surgical management is important to avoid putting the implant at risk for deep periprosthetic infection.

F. Stiffness
1. To prevent stiffness, it is critical to follow patients closely during the early postoperative period to determine whether further intervention, such as manipulation under anesthesia, might be required.
2. Patient factors
   a. Preoperative ROM
   b. Body habitus

c. Female sex
d. Extreme varus
e. Young age
f. Postoperative ROM
    Patient compliance
    Pain tolerance

3. Technical factors associated with poor ROM
    a. Overstuffing the patellofemoral joint
    b. Mismatched gaps (excessive tightness in flexion and/or extension)
    c. Component malposition
    d. Joint line elevation
    e. Excessive tightening of the extensor mechanism at closure
4. Postoperative complications associated with poor ROM
    a. Infection
    b. Delayed wound healing, resulting in delayed therapy
    c. Hemarthrosis
    d. Component failure
    e. Periprosthetic fracture
    f. Complex regional pain syndrome
    g. Severe heterotopic ossification
5. When patients present with less than 90° of motion in the first 6 weeks following surgery, manipulation should be considered if progressive improvement is not demonstrated.
    a. Manipulation should be performed carefully because overly aggressive manipulation can result in fracture or injury to the extensor mechanism.
    b. Manipulation is associated with greater risk and lower benefit when performed later than 3 months after surgery.
6. Late knee stiffness may require open procedures, such as scar excision, quadricepsplasty, and even revision of the components. The success of revision TKA for stiffness is limited.

IX. Medial Unicompartmental Knee Arthroplasty

TABLE 4

Long-Term Results of Unicompartmental Knee Arthroplasty Outcome Studies

Author	Year	Prosthesis	No. of Knees	Survivorship [a]		
				10 yr	15 yr	20 yr
Marmor	1988	Marmor	228	70%	—	—
Scott et al	1991	Unicondylar	100	85%	—	—
Capra and Fehring	1992	Marmor, Compartmental II	52	94%	—	—
Heck et al	1993	Marmor, Zimmer I and II	294	91%	—	—
Munk and Frokjaer	1994	Marmor	68	92%	—	—
Weale and Newman	1994	St. Georg	42	90%	88%	—
Cartier	1996	Marmor	60	93%	—	—
Ansari et al	1997	St Georg	461	96%	—	—
Tabor and Tabor	1998	Marmor	67	84%	79%	—
Murray et al	1998	Oxford	144	98%	—	—
Squire et al	1999	Marmor	140	—	90%	84%
Svard and Price	2001	Oxford	94	95%	—	—
Gioe et al	2003	Nine different designs (community-based)	516	89%	—	—
Swienckowski and Pennington	2004	Miller-Galante (patients younger than 60 yr)	46	92%	—	—
Berger et al	2005	Miller-Galante	49	98%	95.7% [b]	—

[a]Based on revision for any reason.

[b]13-yr survivorship reported.

Reproduced from DeshmukhRV , ScottRD : Unicompartmental knee arthroplasty: Long-term results, in Barrack BoothRLRE , LonnerH , McCarthyJC , MontMA , RubashHE , eds: *Orthopaedic Knowledge Update*: Hip and Knee Reconstruction, ed 3. Rosemont, IL, American Academy of Orthopaedic Surgeons, 2006, pp 59-70.

A. Overview and indications
    1. Unicompartmental knee arthroplasty has been a controversial procedure since its introduction 30 years ago.
    2. The indications tend to vary widely.
    3. It can be considered as an alternative to TKA and osteotomy when degenerative arthritis involves only one compartment.
    4. Traditionally, the criteria for unicompartmental knee arthroplasty

have limited the procedure to older, thin patients with lower demands and unicompartmental disease.

5. The data suggest that only 6% of patients meet the following early criteria for this procedure:
    a. Noninflammatory arthritis
    b. Less than 10° of varus and less than 5° of valgus
    c. Intact anterior cruciate ligament
    d. At least 90° of flexion
    e. No evidence of mediolateral subluxation
    f. Flexion deformity of less than 15°
    g. Correctable deformity
    h. Stress radiographs demonstrate no collapse of the opposite compartment.
    i. Patellofemoral cartilage changes grade III or lower and asymptomatic
    j. Less than 90 kg in weight
6. Age and weight have remained the most controversial criteria.
7. Until recently, unicompartmental knee arthroplasty was performed in only 5% of patients for whom knee arthroplasty was indicated.
8. Efforts have been made to expand the indications for this procedure to include younger patients as well as patients with moderate involvement of the compartments not being resurfaced.
9. The procedure offers advantages for two distinct patient populations.
    a. Middle-aged patients, as an alternative to osteotomy
        A higher initial success rate
        Fewer early complications
        More acceptable cosmetic appearance
        Longer-lasting result
        Easier conversion to TKA
    b. Octogenarians (not expected to outlive the implant)
        Faster recovery
        Less blood loss
        Less medical morbidity

Less expensive procedure

B. Technique
   1. Overcorrection should be avoided; the mechanical axis should be undercorrected by 2° to 3°.
   2. Peripheral and notch osteophytes are removed.
   3. Minimal bone is resected.
   4. Extensive releases are avoided, especially release of the deep MCL for medial compartment arthroplasty.
   5. Edge loading is avoided.
   6. Appropriate mediolateral placement is achieved to prevent tibial spine impingement.
   7. A varus tibial cut is avoided to prevent implant loosening.
   8. To prevent a tibial plateau stress fracture from high medial stresses, caution should be used when placing proximal tibial guide pins.

C. Results
   1. First-decade results from studies published from the late 1980s to the early 1990s are highlighted in Table 4.
      a. Ten-year survival rates range from 87.4% to 96.0%.
      b. The standard failure rate in the first decade is 1% per year.
   2. Second-decade results also are highlighted in Table 4
      a. A rapid decline in survivorship is noted.
      b. Fifteen-year survival rates range from 79% to 90%.
   3. Causes of late failure
      a. Opposite compartment degeneration
      b. Component loosening
      c. Polyethylene wear

D. Mobile-bearing unicompartmental knee arthroplasty
   1. Meniscal bearing designs are available that allow increased conformity and contact without constraint, which can result in a substantial decrease in wear.
   2. Excellent survivorship has been demonstrated with these prostheses in some series out to the second decade.
   3. The procedure is technically demanding, and the bearings can dislocate.

X. Lateral Unicompartmental Arthroplasty

A. Has been described for as long as has medial unicompartmental knee arthroplasty
B. Clinical outcomes scores tend to be excellent
C. Truly isolated lateral disease is fairly unusual. Most advocates caution against allowing any patellofemoral disease to be present.
D. The risk of overcorrection is higher than that seen in medial unicompartmental knee arthroplasty because the lateral stabilizers tend to be much more pliable.
E. Because of the mobility of the lateral knee joint articulation, a mobile-bearing implant must not be used in lateral unicompartmental knee arthroplasty.
F. Can be performed through a medial or a lateral arthrotomy, but tibial cuts are difficult to make through the medial arthrotomy. If a lateral arthrotomy is used, the sagittal plane cut may best be made through the patellar tendon (the tendon is cut in line with the fibers).
G. Long-term outcomes are lacking, in part because of the low numbers of appropriate candidates.

XI. Patellofemoral Arthroplasty

A. Indications
    1. Isolated patellofemoral osteoarthritis
    2. Posttraumatic arthrosis
    3. Severe chondrosis (Outerbridge grade IV)
    4. Failed nonsurgical treatment
    5. Patients who are symptomatic during prolonged sitting, stair or hill ambulation, or squatting
B. Contraindications
    1. Inflammatory arthritis
    2. Chondrocalcinosis, with involvement of the menisci or tibiofemoral chondral surfaces
    3. Patients with unrealistic expectations

4. Severe patellar maltracking or malalignment; a realignment procedure is required in concert with or before arthroplasty

C. Results
   1. Most series report 85% good to excellent results.
   2. Failures are associated with uncorrected alignment issues and the progression of tibiofemoral arthritis (25% failure rate at 15-year follow-up in one study).
   3. Some series report higher failure and revision rates as well as poorer functional outcomes, which appear to be correlated to implant design.
   4. Cemented trochlear and all-polyethylene components are not associated with a high rate of loosening. Appropriate patient selection should result in predictable outcomes.

Top Testing Facts

1. Similar survivorship rates are achieved for PCL-retaining and PCL-substituting TKAs at 10- to 12-year follow-up.
2. Similar survivorship rates, ranging from 94% to 97%, are achieved for cemented and noncemented TKAs at 10 to 12 years.
3. Proper balancing of a TKA is achieved after the flexion and extension gaps are symmetric, and the flexion gap is typically measured at 90° of flexion.
4. Peripheral osteophyte resection is an important early step in balancing a varus knee, before any extensive soft-tissue releases are performed.
5. In a knee with severe valgus, a constrained device should be considered when severe valgus deformity is present with an incompetent or attenuated MCL.
6. When balancing a TKA, if tight in extension and flexion, a symmetric gap is present, then more proximal tibia should be cut.
7. If extension is tight and flexion is acceptable, an asymmetric gap is present, and either not enough of the posterior capsule was released or not enough distal femur was resected.
8. Regardless of the TKA implant design used, preoperative ROM remains the most consistent predictor of postoperative ROM.
9. Internal rotation of the tibial component results in external rotation of the tibial tubercle and increases the Q angle, which can result in patellar

maltracking and be a source of chronic postoperative pain and dissatisfaction.

10. Peroneal nerve palsy is most common following TKA performed for a severe, fixed valgus deformity with a flexion contracture.

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CHAPTER 50

Revision Total Knee Arthroplasty

MICHAEL D. RIES MD

RYAN M. NUNLEY MD

I. Causes of Implant Failure

A. Osteolysis

1. UHMWPE wear rate—Many factors can affect the wear rate c ultra-high–molecular-weight polyethylene (UHMWPE) in total kne arthroplasty (TKA).
    a. Sterilization method
    b. Manufacturing method (conventional or cross-linked)
    c. Presence of third-body debris
    d. Motion between the modular tibial insert and metal tray (resulting in backside wear)
    e. Roughness of the femoral implant counter-face
    f. Alignment and stability of the knee arthroplasty
    g. Biomechanical demands or activity level of the patient
2. Polymethyl methacrylate (PMMA) cement debris.
    a. PMMA cement debris can contribute to osteolysis.
    b. Cement debris can be caused by motion between the implant and cement due to loosening or debonding.
    c. When osteolysis does occur in TKAs, it can result in the development of expansile bone defects, with substantial compromise of the bone stock of femoral condyles and the tibial metaphysis.
3. Biologic response
    a. Patients may respond differently to wear debris, but smaller

wear particles (<10 mm) are more readily absorbed by macrophages, which then release cytokines.

b. The cytokines signal osteoclasts to resorb bone, resulting in well-demarcated cystic lesions in the periarticular bone (Figure 1).

c. Femoral osteolysis can be more difficult to detect on an AP radiograph because the lesions are typically located in the posterior condyles and are obscured by the femoral implant, whereas tibial lesions are usually more readily visible.

B. Loosening

1. Type of fixation

a. Both noncemented and cemented TKAs have resulted in satisfactory outcomes.

Early loosening is a more common complication of noncemented TKA but may be improving with the introduction of porous metal ingrowth surfaces.

Cement fixation is currently used in the United States for most primary TKAs.

b. Early failure after TKA usually results from infection, malalignment, instability, and arthrofibrosis. Late failure after TKA results from wear more often than from loosening, although the two mechanisms can be related. Osteolysis that results in loss of bony support for the prosthetic components or that disrupts the bone-implant interface may result in mechanical loosening.

2. Alignment

a. Limb malalignment causes asymmetric loading of the knee, which also can result in early loosening. Loosening appears to occur more frequently with varus malalignment than with valgus malalignment.

b. Tibial loosening typically presents as a change in implant position or alignment associated with varus or valgus subsidence of the component. Pain occurs more during weight-bearing activity than at rest, and tenderness is localized

to the tissues in proximity to the loose component.

C. Arthrofibrosis
    1. The process by which pathologic scar tissue forms after TKA and restricts functional range of motion is relatively poorly understood.
    2. Arthrofibrosis may develop in patients who have normal intraoperative range of motion (ROM). However, passive flexion extension, or both can become restricted and painful, sometimes several weeks after surgery following an early postoperative period of normal motion.
    3. The response to both nonsurgical and surgical treatment is often unsatisfactory.
    4. Arthrofibrotic scar contains dense fibrous tissue with abundant fibroblasts.
    5. Heterotopic bone is frequently found in patients with arthrofibrosis.
    6. Stiffness may result from inadequate postsurgical pain management or rehabilitation or from a biologic process that causes rapid proliferation of scar tissue.
    7. Genetic factors also may play a role, although it is difficult to predict which patients are at increased risk for arthrofibrosis after TKA.
    8. Surgical technique also can contribute; oversizing the femoral implant, overstuffing the patella, or rotational malalignment can play a role.

D. Instability
    1. Mediolateral instability
        a. Gross instability caused by loss of collateral ligament support may result from intraoperative collateral ligament laceration, postsurgical trauma, or gradual attenuation over time, especially in the setting of polyethylene wear.
        b. Stress radiographs can help identify or confirm collateral ligament disruption.
        c. Loss of collateral ligament support requires an implant constrained to varus and valgus stress. If ligament disruption is

identified intraoperatively, however, then primary repair and postsurgical bracing treatment without a fully constrained implant can provide satisfactory results.

2. Flexion instability
    a. Soft-tissue laxity can develop after surgery despite appropriate mediolateral and flexion-extension gap balancing.
    b. Both posterior cruciate–retaining (CR) TKAs and posterio cruciate–substituting (PS) TKAs require sacrifice of the anterior cruciate ligament, which can result in flexion instability despite intact collateral ligaments.
    c. Patients with symptomatic flexion instability usually report vague pain and swelling after activity and have laxity to varus and valgus stress in flexion. Radiographs typically demonstrate "paradoxical motion," or anterior subluxation of the femur on the tibia in flexion, rather than roll back (Figure 2).
    d. Symptoms may be controlled with activity restrictions, bracing treatment, NSAIDs, and muscle-strengthening exercises.
        If these nonsurgical measures fail, revision TKA is appropriate.
        Conversion of a CR to a PS TKA, or upsizing th polyethylene liner, is beneficial in most revision situations, but more reliable results are achieved with revision to a more constrained TKA if the flexion-extension gap balance is not restored using less articular constraint.

E. Infection—Infection associated with TKA is described in Chapter 121.

FIGURE 1 AP radiograph of the knee demonstrates particulate wear debris–induced osteolysis resulting in a well-demarcated uncontained lateral tibial defect (arrows).

FIGURE 2 Flexion lateral radiograph of a posterior cruciate-retaining total knee arthroplasty demonstrates anterior subluxation of the femur on the tibia or "paradoxical motion," which often is associated with flexion instability.

II. Evaluation of the Painful Total Knee Arthroplasty

A. Overview

1. The source of pain after TKA may be difficult to determine. The workup should include evaluation for infection, neurogenic pain, referred pain from the hip or back, and mechanical sources of pain.
2. Evaluation should include a thorough history and physical examination, laboratory studies, and plain radiographs. Additional nuclear medicine studies or specialized imaging also may be necessary.
3. A history of pain that develops immediately after surgery and then

persists (no pain-free interval) and pain with rest as well as weight bearing suggest an inflammatory and/or neurogenic source of pain.

4. Pain during weight-bearing activity or knee motion is consistent with a mechanical source of pain.

B. Infection and neurogenic pain

1. Infection is a common source of pain and must be ruled out first in all patients. It is usually associated with an elevated erythrocyte sedimentation rate and C-reactive protein level and can be detected by aspiration (cell count with differential and culture). However, false-negative and false-positive results can occur, and additional imaging studies may be necessary.
2. Pain associated with localized warmth and swelling that occurs more after activity and is relieved with rest is less consistent with infection and more typical of soft-tissue inflammation resulting from postsurgical rehabilitation of the soft tissues during exercise.
3. Pain that is described as burning or numbness and is nonfocal on examination or improves with analgesic medications or those for neuropathic pain (gabapentin, pregabalin, and tricyclic antidepressant medications) and with local trigger point, or epidural injections supports the diagnosis of neurogenic pain.

C. Mechanical causes of pain

1. Overview
   a. Mechanical causes of early pain after TKA include patella maltracking, patellar clunk or crepitus, tibiofemoral instability, periprosthetic fracture, or occult implant loosening.
   b. Patellar problems are usually evident on physical examination because the location of pain is restricted to the patellofemoral joint. These patients also may present with reduced knee ROM and flexion.
   c. Patellar clunk is a complication of PS TKA and occurs when a fibrous nodule at the inferior pole of the patella catches in the trochlear groove during knee extension. This was a problem with older implant designs but is rarely described with newer ones. Patellar crepitus is more common with current PS

designs, which may cause anterior knee pain. Symptoms are relieved by open or arthroscopic excision of the fibrous nodules and synovium.

d. Patellar maltracking and subluxation may result from dehiscence of the medial retinacular arthrotomy, femoral or tibial component internal rotation, or patellar component malpositioning.

e. Rotational orientation of the femoral implant may be assessed to some extent on an axial view of the patella, but it is better quantitated using CT with metal artifact reduction. Symptomatic patellar subluxation or maltracking resulting from internal rotation of the femoral or tibial components requires revision of the malaligned components (Figure 3).

2. Flexion instability

a. History and physical examination

A history of pain and effusion that occurs after activity and is relieved with rest is consistent with flexion instability.

Flexion instability caused by intact but attenuated soft-tissue constraints can be detected on physical examination by varus and valgus stress testing. Laxity is typically more evident in flexion than full extension as the posterior capsule and hamstrings contribute to stability in extension.

b. Radiographic evaluation

Flexion instability is more common with CR TKAs than wit PS TKAs and is associated with paradoxic motion or rolling forward of the femoral implant, which can be seen on flexion lateral radiographs as anterior subluxation of the distal femur on the tibia (Figure 2).

Complete dislocation of a PS knee presents with gross instability in flexion on physical examination and posterior displacement of the tibia on the femur (Figure 4). This is more common when excessive posterior slope occurs with the tibial cut and with some PS-designed TKAs.

3. Loosening and wear
    a. History and physical examination
        Pain that develops late after TKA is more often associatec with loosening or UHMWPE wear, although lat hematogenous infection can occur and should be included in the differential diagnosis.
    b. Radiographic evaluation
        Wear can be seen radiographically as asymmetric height of the tibial plateaus, although rotation and flexion of the knee can alter the projected height of the joint space, making radiographic measurements of wear inaccurate.
        Loosening occurs when subsidence or displacement of the component or a complete or progressive radiolucency at the implant and bone interface occurs.

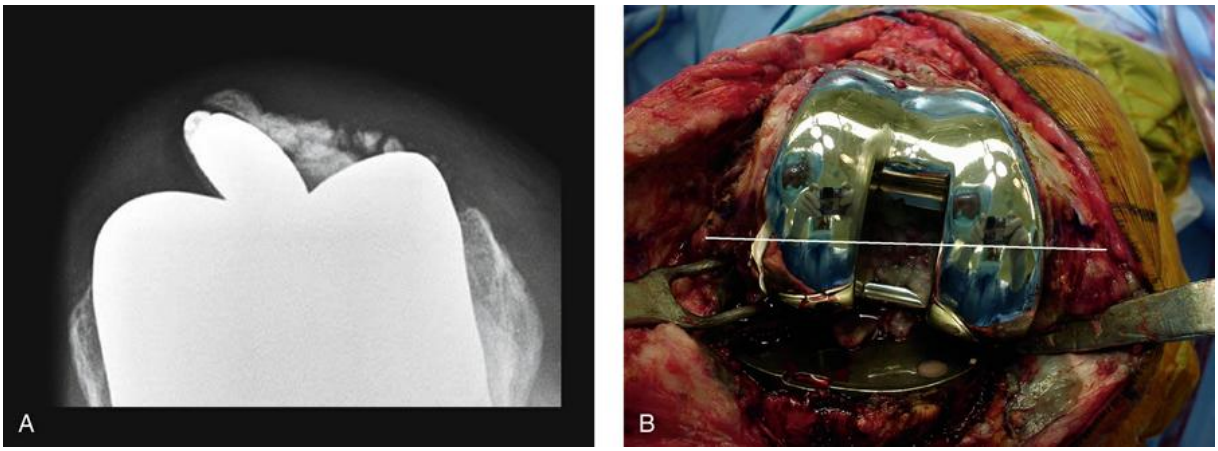

FIGURE 3 Images depict internal rotation of the femoral implant. **A,** Radiograph demonstrates considerable patellar tilt associated with an internally rotated femoral implant. **B,** Intraoperative view of the same knee demonstrates that the femoral implant is internally rotated relative to the epicondylar axis (white line).

FIGURE 4 Lateral radiograph demonstrates dislocation of a posterior cruciate-substituting femoral implant over the tibial post.

III. Classification of Bone Defects

A. Assessment of tibial and femoral bone loss
   1. Preoperative planning
      a. Bone loss should be assessed during the preoperative planning process and during the revision surgery.
      b. Preoperative evaluation often underestimates the extent of bone loss; nonetheless, appropriate materials must be available for reconstruction during revision TKA.
   2. Intraoperative evaluation is the most accurate method of assessing remaining bone stock and determining the most appropriate method of reconstruction. This assessment should take place after removal of implants and extensive débridement of membrane and necrotic bone.
   3. Classification of defects
      a. Bone loss may be classified by defect size, location, depth, and the presence or absence of an intact peripheral rim of bone on which to place a prosthesis or contain bone graft.
      b. The Anderson Orthopaedic Research Institute bone defec classification system (Table 1) provides some guidelines for the management of bone defects.
         The classification is applied independently to the femur and tibia (Figure 5).
         It is based on the amount of metaphyseal bone that remains following implant removal.
         It does not specify whether the defects are contained or uncontained, an important consideration in the use of particulate graft, which is more readily impacted into contained defects.

TABLE 1

Anderson Orthopaedic Research Institute Bone Defect Classification System

Defect Type	Characteristics	Management

1	Metaphyseal bone is intact and supportive of the prosthesis Small contained defects may be present	Contained defects can be filled with morcellized bone graft or cement
2	Deficiency of metaphyseal bone compromises implant support	Requires a revision prosthesis with modular augmentation and/or structural bone graft in addition to extended intramedullary stems to achieve mechanical stability of the implant
3	Deficiency of entire metaphyseal region	Requires structural bone graft, a segmental metal augmentation device, or a tumor-type prosthesis for revision The tibial defect shown in Figure 1 would be considered a type 3 defect

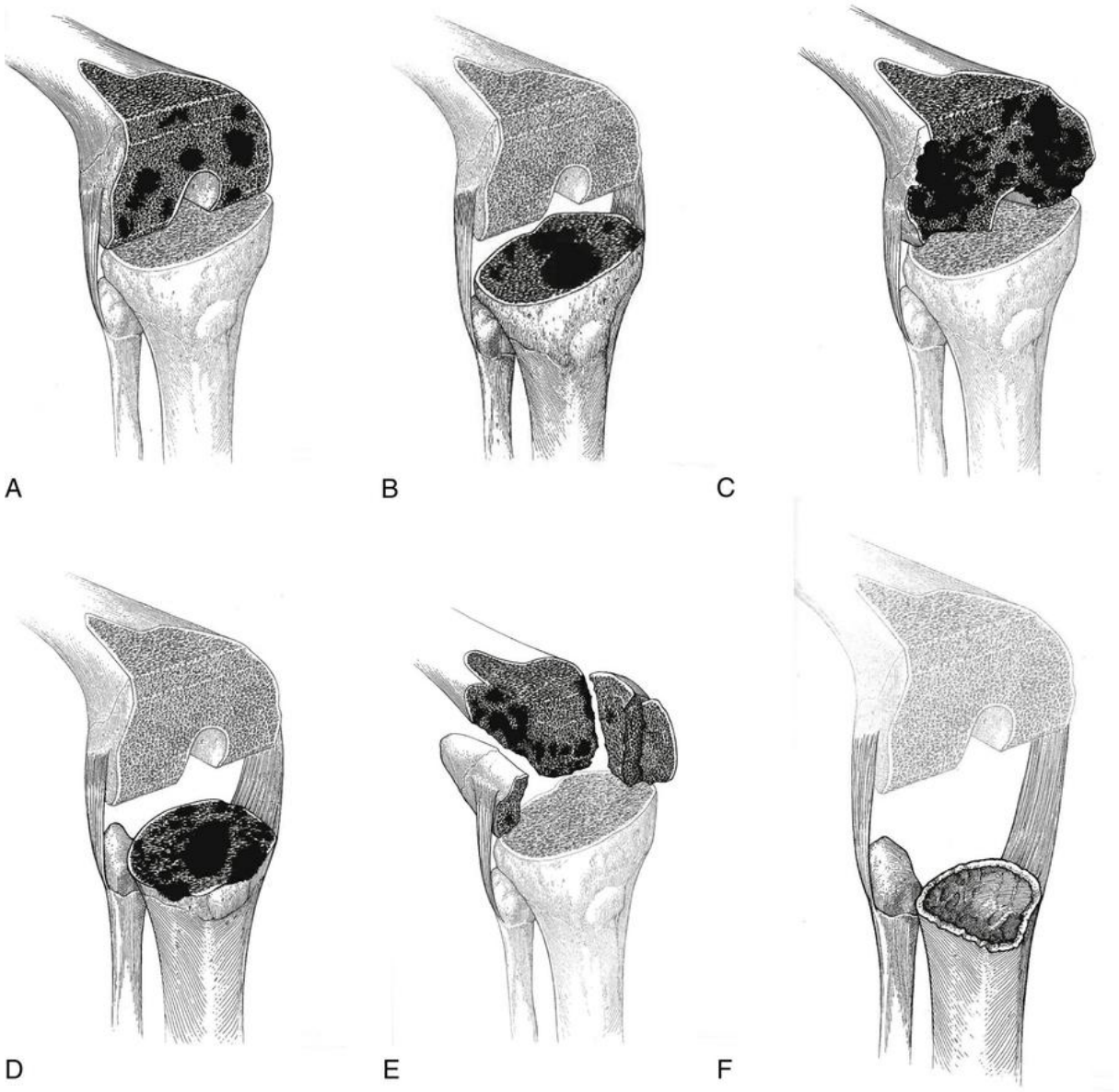

FIGURE 5 Illustrations demonstrate the Anderson Orthopaedic Research Institute classification of bone defects. **A,** Type 1, femoral defect. **B,** Type 1, tibial defect. **C,** Type 2, femoral defect. **D,** Type 2, tibial defect. **E,** Type 3, femoral defect. **F,** Type 3, tibial defect.(Reproduced with permission from EnghGA : Bone defect classification, in: EnghGA , RorabeckCH , eds: Revision Total Knee Arthroplasty. Baltimore, MD, Lippincott Williams & Wilkins, 1997, pp 63-120.)

IV. Surgical Treatment

A. Medial parapatellar approach
   1. Most revision TKAs can be exposed adequately through a media parapatellar arthrotomy.

2. Exposure can be facilitated by mobilizing the extensor mechanism through the removal of retropatellar adhesions and the performance of lateral retinacular release and subperiosteal dissection of the proximal medial tibia. This permits more tibial external rotation. For knees with limited preoperative motion, however, more extensile exposure is required to avoid patellar tendon avulsion.

B. Extensile exposure—Extension of the medial parapatellar arthrotomy can be performed proximally, with a rectus snip, or distally, with tibial tubercle osteotomy.
   1. Rectus snip (Figure 6)
      a. An oblique medial to lateral transection of the rectus tendon at the proximal portion of the arthrotomy (rectus snip) does not appear to compromise long-term knee function and can relieve some of the tethering effect of a contracted extensor mechanism.
      b. The exposure afforded with a rectus snip is not as extensile as that with a V-Y quadriceps turndown or tibial tubercle osteotomy.
   2. Tibial tubercle osteotomy
      a. A long osteotomy of the tibial tubercle in continuity with the tibial crest and attached anterior compartment muscles maintains vascularity of the osteotomized bone fragment and a distal soft-tissue tether to prevent proximal migration of the bone fragment. Reliable union rates have been reported using this osteotomy technique.
      b. Tibial tubercle osteotomy is best indicated for cases with adequate tibial bone stock. Those with severe osteolysis or osteoporosis of the proximal tibia, in which fixation of the osteotomy would be compromised, may be better treated using a proximal rectus snip.

C. Management of bone defects
   1. Reconstruction options—Bone defects can be reconstructed with morcellized or structural allograft, synthetic bone graft substitutes,

cement, cemented metal augments, porous ingrowth cones, or a combination of materials.

2. Contained defects
    a. Small contained defects can be filled with cement or bone graft.
    b. Large contained defects can be treated effectively with highly porous ingrowth cones. Biologic fixation of host bone to the porous cone may enhance durability of the reconstruction.
    c. Bone grafting can restore bone stock and may be more appropriate for younger patients who could require future revision surgery.
3. Noncontained defects
    a. Noncontained defects imply loss of cortical, structurally supportive bone and should be managed by restoration of structural stability. This requires augmentation of the defect with metal augments or cones (Figure 7).
    b. Massive segmental bone loss may require reconstruction with a tumor prothesis.
4. Stem fixation
    a. Stemmed components are necessary to provide additional implant stability if metaphyseal fixation is compromised by bone loss or to protect bone grafts from weight-bearing stresses during postoperative healing.
    b. Stems may be cemented or noncemented and have variable lengths. The choice of stem length and fixation depends on many factors, including
        The mechanical stability of metaphyseal fixation achieved
        The quality of diaphyseal and metaphyseal bone stock
        The weight-bearing capability of bone grafts or augments used
        The biomechanical demands of the patient
        The amount of implant constraint

D. Choice of implant constraint—Revision TKA may be performed using an unconstrained CR or PS implant, a constrained PS prosthesis, or fixed or rotating hinge mechanism.

1. Unconstrained CR implant
    a. Requires an intact posterior cruciate ligament and collateral ligament support
    b. May be appropriate for revision of a failed unicompartmental arthroplasty with minimal bone loss and intact ligament supports.
2. Unconstrained PS implant—requires intact collateral ligaments with balanced mediolateral soft tissues and flexion and extension spaces.
3. Constrained PS implant or hinge
    a. If one or both collateral ligaments are deficient or adequate soft-tissue balance cannot be achieved, then additional prosthetic constraint is appropriate.
    b. A constrained PS prosthesis includes a wide tibial post that fits tightly into the femoral implant box. This constrains varus-valgus motion and rotation.
    c. A rotating hinge prosthesis contains an axle that links the femoral and tibial components and provides stability to varus and valgus stress but permits rotation.
    d. Because the constrained PS relies on the UHMWPE post t provide constraint, whereas the hinge uses a metal axle, the hinge is generally considered to be more rigidly constrained and is indicated for cases with complete loss of collateral ligament support.
    e. The hinge mechanism also limits hyperextension; thus, a hinge may be a better choice than a constrained PS device if the extensor mechanism is deficient because damage to the tibial post can occur if a constrained PS prosthesis is hyperextended.
    f. Most hinge implants require more femoral bone removal than a constrained PS prosthesis to accommodate the hinge mechanism.
    g. Because of the increased torque on the femoral and tibial implants with the constrained PS or hinge prosthesis, stems should be used to reduce mechanical loosening.

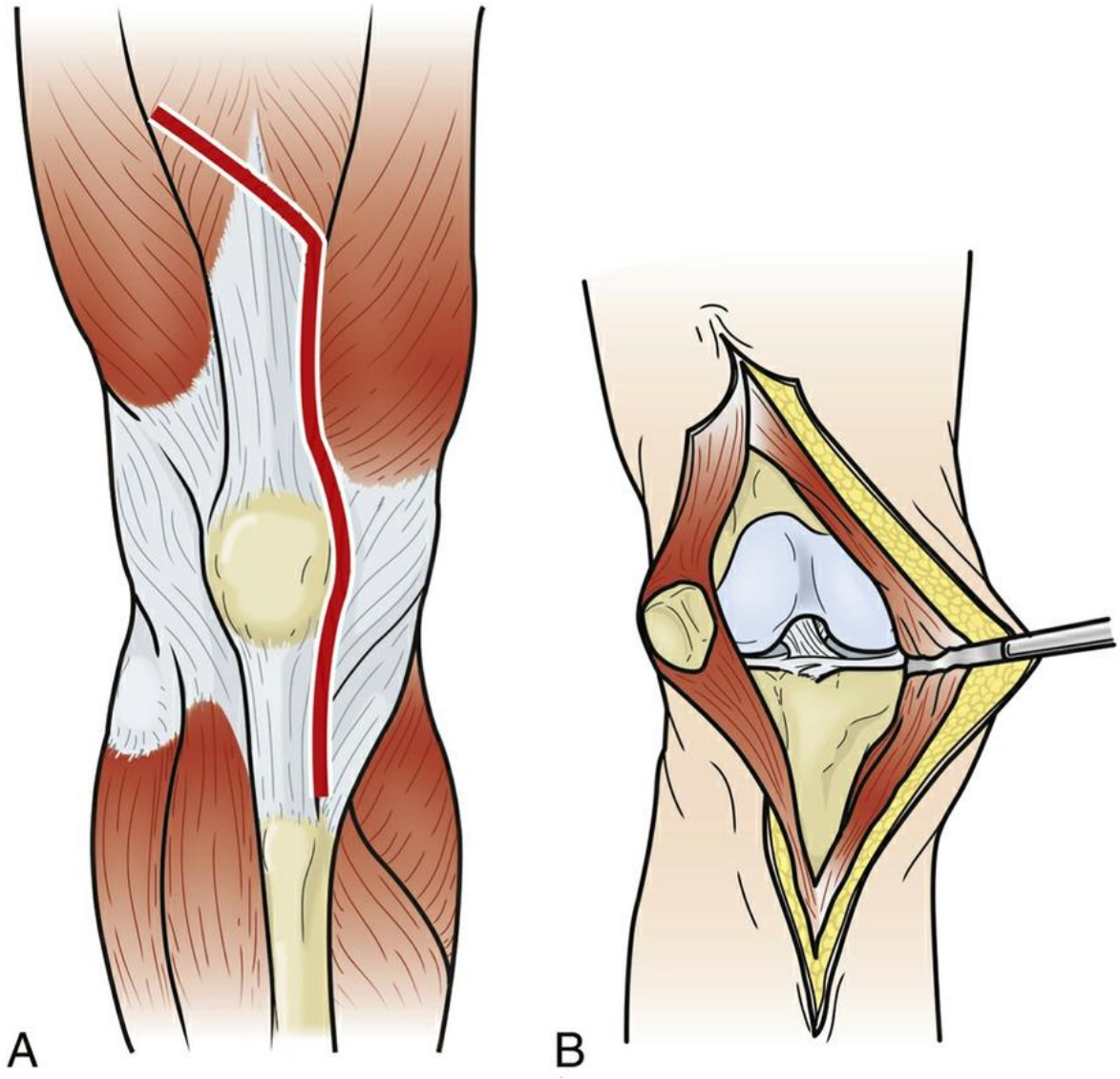

FIGURE 6 Illustrations show the exposures for revision total knee arthroplasty. **A,** A rectus snip. The rectus tendon is incised obliquely to decrease the tethering effect of the extensor mechanism and permit exposure of the knee with less tension on the patellar ligament insertion at the tibial tubercle. **B,** After release of the rectus tendon proximally, the patella is subluxated laterally and the joint is exposed.(Reproduced from SeidensteinA , ScuderiS , ScuderiGR : Revision total knee arthroplasty via quadriceps snip, in: FlatowE , ColvinAC , eds: Atlas of Essential Orthopaedic Procedures. Rosemont, IL, American Academy of Orthopaedic Surgeons, 2013, p 359.)

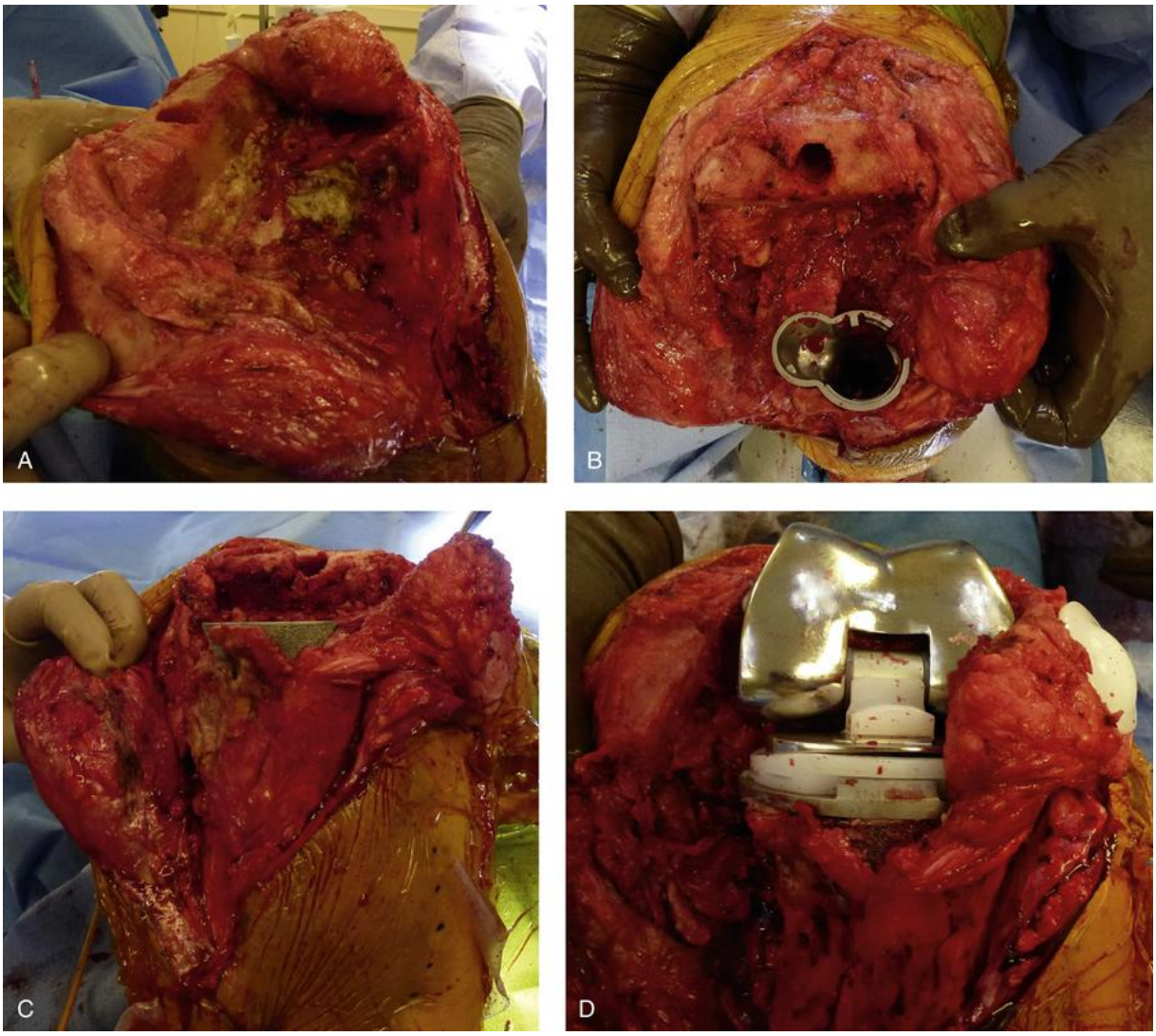

FIGURE 7 Intraoperative photographs demonstrate an uncontained medical tibial defect treated with a cone. **A,** Intraoperative photograph illustrates an uncontained medial tibial (Anderson type 2) bone defect. **B,** The intramedullary canal and defect are prepared with instruments and a cone trial placed to augment the defect. **C,** The porous coated cone is press fit to restore the area of tibial bone loss. **D,** The final implants are cemented into the cone allowing bone ingrowth into the outer porous coated surface of the cone.

V. Complications

A. Pain
   1. Etiology and prognosis
      a. Activity-related pain after revision TKA can be expected for 6 to 12 months or more after surgery.
      b. Pain associated with soft-tissue inflammation should gradually

diminish during this time.

c. Chronic neurogenic pain that is not consistent with a mechanical source or occult infection may occur after TKA.
d. Patients with greater preoperative pain appear to have an increased risk of developing chronic postoperative pain.

2. Treatment
   a. Persistent neurogenic pain should be treated with a multimodal pain management approach, local or epidural injections, and manipulation, if associated with stiffness. The response to treatment is often poor, however, and requires a long-term pain management program.
   b. Surgical treatment of a chronically painful TKA with no mechanical source or evidence of infection is usually associated with a poor outcome.

B. Stiffness
   1. Infection must be ruled out first for all patients with a stiff, painful TKA.
   2. Early rehabilitation including passive-assisted and active-assisted ROM is important to avoid limited motion after TKA.
   3. If motion remains restricted, manipulation or, occasionally, revision surgery for arthrofibrosis may be necessary. Manipulation is more reliable for loss of flexion than for loss of extension.
   4. Arthroscopic resection of arthrofibrotic scarring and open débridement with tibial insert exchange has been associated with variable results.
   5. Modest gains in ROM can be obtained with revision TKA along with wide resection of periarticular arthrofibrotic scarring and downsizing of the femoral implant, although pain may still persist.

C. Infection
   1. Superficial infection that clearly does not involve the knee joint can be treated with antibiotics alone, whereas intra-articular infection requires prompt surgical management.
   2. Early infection can be treated with débridement, liner exchange, and retention of the components, whereas late or chronic infection

requires one-stage or two-stage exchange of the prosthetic components, as described in Chapter 121.

D. Extensor mechanism disruption
    1. Disruption of the extensor mechanism after TKA can occur from patellar tendon tear or avulsion, patellar fracture, or quadriceps tendon tear.
    2. Primary repair of a chronic extensor mechanism disruption without autogenous or allograft soft-tissue augmentation is associated with a high risk of failure.
    3. Semitendinosus or fascia lata autograft can be used to augment the primary repair.
    4. Extensor mechanism allograft using Achilles tendon (tendon with calcaneal bone block in continuity) or complete extensor mechanism allograft (tibial tubercle, patellar tendon, patella, and quadriceps tendon in continuity) has been reported most frequently for extensor mechanism disruption after TKA; failure caused by intraoperative undertensioning and graft attenuation can occur.
    5. The graft should be sutured in maximal tension with the knee in full extension, avoiding intraoperative assessment of the repair by flexing the knee. Postsurgical ROM is restricted for 6 weeks after surgery to minimize problems associated with graft attenuation.
    6. Marlex mesh can be used as an alternative to allograft tissue, to reconstruct the extensor mechanism. Distal fixation of the mesh to the tibia is achieved with screw fixation or intramedullary cement, while the proximal mesh is sutured to the quadriceps tendon.
    7. The medial gastrocnemius muscle and tendon can also be used to reconstruct the extensor mechanism and to provide soft-tissue coverage, particularly in the setting of infection or wound necrosis. The distal tendinous portion is harvested along with the medial muscle belly and retracted proximally over the anteromedial aspect of the knee, allowing attachment to the remaining extensor mechanism.

VI. Salvage Procedures

A. Arthrodesis
   1. Arthrodesis is a viable salvage option to permit ambulatory function after failed revision TKA. Bone loss usually results in considerable shortening and leg-length inequality, however, and the loss of ROM is a substantial functional impairment for many elderly patients or those with ipsilateral hip, ankle, or back problems.
   2. Arthrodesis techniques include intramedullary rodding with a long rod from hip to ankle or modular compression devices inserted through the knee, dual plating, and external fixation. Each of these techniques can result in successful arthrodesis, but more reliable results have been reported with intramedullary rodding or dual plating.
   3. Additional options include intercalary tumor prosthesis components, which allow segmental bodies to bridge areas of massive bone loss, reduce the leg-length inequality, and minimize the redundancy of the soft tissues.

B. Amputation
   1. A salvage procedure reserved for recurrent infections, massive bone loss, or incompetent extensor mechanism in patients who are not candidates for other reconstructive options.
   2. Many patients consider transfemoral amputation too disfiguring to accept.
   3. Amputation does, however, provide a single definitive treatment of most complex failed revision TKAs.
   4. A well-fitting prosthesis may permit more comfortable sitting activity than arthrodesis and comparable ambulatory function.

Top Testing Facts

1. Osteolysis after TKA can result from a biologic response to particulate UHMWPE, metal, and cement debris.

2. Early failure after TKA usually results from infection, malalignment, instability, and arthrofibrosis, whereas late failure more typically occurs from wear and loosening.
3. Pain during weight-bearing activity after TKA suggests a mechanical cause such as loosening or instability, whereas pain that occurs both at rest and with weight bearing suggests an inflammatory source such as infection or neurogenic pain.
4. If exposure during revision TKA is difficult and concern is present that the patellar ligament may avulse from its insertion, the exposure can be extended proximally with a rectus snip or distally with a long tibial tubercle osteotomy.
5. Cancellous bone grafts heal and revascularize more effectively than solid structural bone grafts and are most appropriate for small contained cavitary defects.
6. Large uncontained bone defects can effectively be treated with porous ingrowth cones or metal augments.
7. Revision TKA for arthrofibrosis can be expected to result in modest gains in ROM, but pain may not improve.
8. Reconstruction of a chronically disrupted extensor mechanism after TKA requires soft-tissue augmentation with autogenous or allograft tissue, or Marlex mesh in addition to primary repair.
9. When using an extensor mechanism allograft or Marlex mesh for extensor mechanism disruption, the graft should be sutured in maximal tension with the knee in full extension and immobilized in full extension for at least 6 weeks (Figure 8).

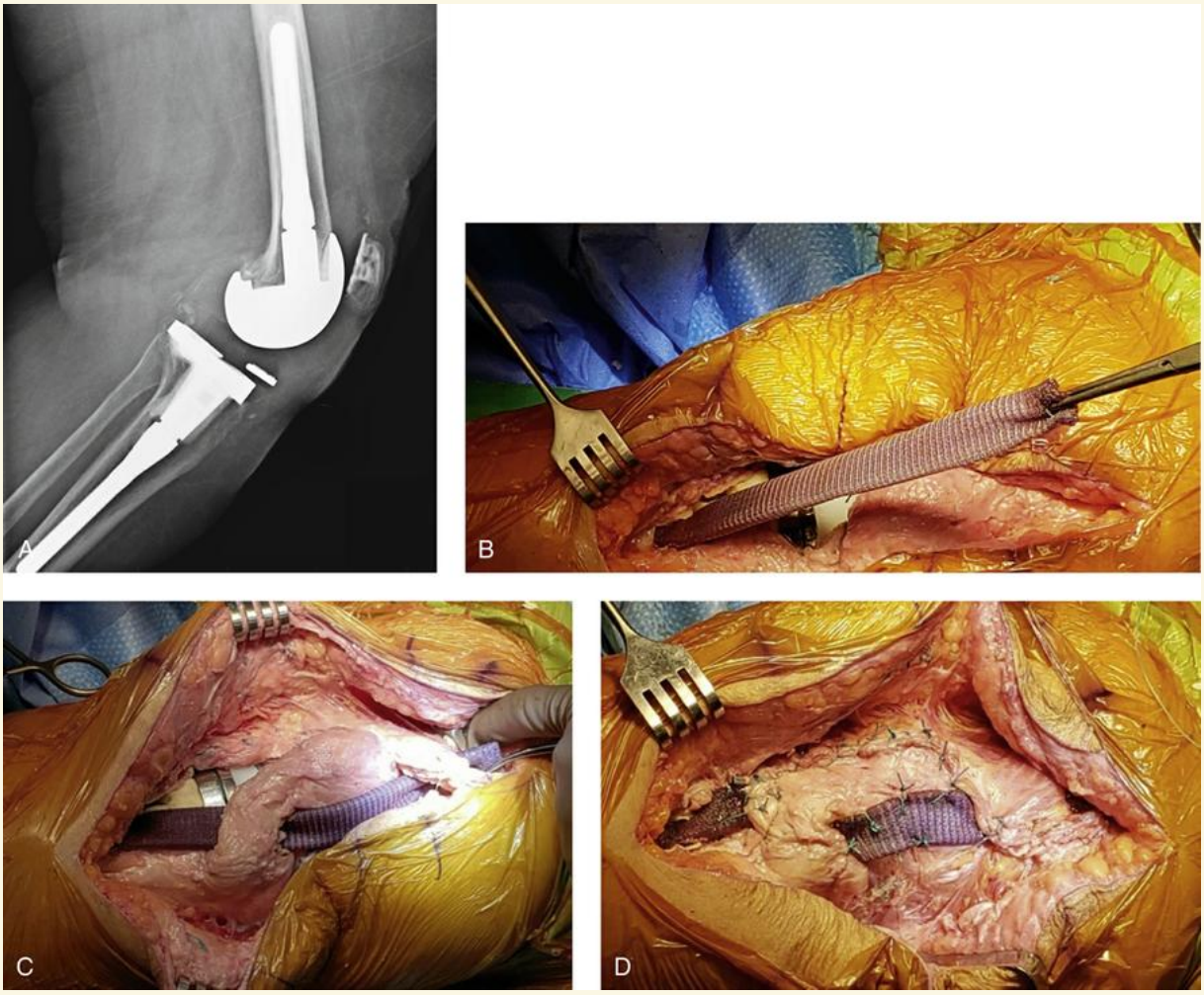

FIGURE 8 Illustrations demonstrate Marlex mesh reconstruction of the extensor mechanism. **A,** Preoperative lateral radiograph shows mechanical failure of prior revision total knee arthroplasty (TKA) and disruption of the patellar ligament with patella alta. **B,** Intraoperative photographs. **B,** Intraoperative photograph shows the Marlex mesh cemented into the tibial canal with the revision tibial stem and retracted proximally demonstrate that distal fixation of the mesh is secure. **C,** The mesh is woven deep to the attenuated patellar ligament, over the anterior surface of the patella, and deep to the quadriceps tendon. **D,** The vastus medialis is advanced distally ober the proximal Marlex mesh.

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CHAPTER 51

Biomechanics and Wear in Joint Arthroplasty

ANDREW BODROGI MD, FRCSC

VICKAS KHANNA MD, MHA, FRCSC

MARIO LAMONTAGNE PHD

PAUL BEAULÉ MD, FRCSC

I. Overview

A. Tribology is the science and technology of friction, lubrication, and wear in interacting surfaces in relative motion.

B. Principles of wear

1. Types of wear include adhesive and abrasive wear, fatigue, and delamination.
2. Adhesive wear predominates in the metal-on-polyethylene bearings used in total hip arthroplasty (THA). Metal-on-polyethylene has been the benchmark in bearing materials for the past four decades.
3. Delamination, abrasion, and adhesive wear are commonly seen with total knee arthroplasty (TKA).
4. There are four modes of wear: (1) between primary bearing surfaces as intended by the designer; (2) between one bearing surface and a nonbearing surface, eg, femoral head against cup rim with joint microseparation; (3) third-body wear, eg, bone cement particles; and (4) between two nonbearing surfaces, eg, backside wear in TKA or femoral neck impingement on acetabular rim.
5. Hip and knee joint simulators are the accepted means for obtaining preclinical test data on wear performance. They have been shown to

produce wear particles of similar size and shape to those observed in vivo.

6. Wear is measured periodically and gravimetrically on the basis of the small amount of weight that a material loses during its use, with 1 million cycles of test use equal to 1 year of clinical use; however, recent literature has shown that some patients experience nearly 2 million cycles of activity per year.

II. The Hip Joint

A. Wear at the hip joint
   1. It is well accepted that polyethylene debris produced by the sliding motion of the femoral head within the polyethylene lining of the acetabular cup is responsible for osteolysis of the bone surrounding the THA and subsequent failure of the prosthesis. This led to the development of ceramic-on-ceramic and metal-on-metal bearings (also known as hard-on-hard bearings) and more wear-resistant polyethylene.
   2. In addition to the debris generated from wear at the articulating surface, relative motion at modular junctions as well as unintentional contact from impingement can generate substantial debris.

B. Biomechanics and kinematics
   1. Motion at the hip joint
      a. The hip joint is inherently stable because of its relatively rigid ball-and-socket configuration and high conformity. Nonetheless, great mobility of the hip joint is required to perform normal activities of daily living.
      b. Hip range of motion (ROM) includes motion in the sagittal frontal, and transverse planes.

         In the sagittal plane, the flexion-extension motion can exceed 145° with the knee in flexion.

         In the frontal plane, the abduction arc can be 120°. With

training, it can reach 180°.

In the transverse plane, the arcs of internal and external rotation are approximately 30° and 60°, respectively.

c. Angles of the hip joint during various activities have been studied, and high degrees of flexion have been measured (squatting: 95.4° of flexion, 28.2° of abduction, 25.7° of external rotation; kneeling: 73.9° of flexion, 25.3° of abduction, 28.1° of external rotation; sitting cross-legged: 85.4° of flexion, 36.5° of abduction, 40.3° of external rotation). The ROMs required by most subjects to complete these activities are greater than can be accommodated by existing prostheses.

2. Surface motion
   a. Surface motion in the hip joint can be considered as gliding of the femoral head on the acetabulum.

      This gliding occurs with the pivoting of the ball-and-socket joint in three planes around the center of rotation of the joint in the femoral head.

      Some authors have suggested that most of the gliding occurs on the superior quadrant of the femoral head.

   b. If the gliding of the femoral head within the acetabulum is incongruent, the resulting shear force may not be parallel to the surface, and the articular cartilage may be abnormally compressed, leading to osteoarthritis. This is the case in cam-type femoroacetabular impingement, in which an aspherical femoral head creates outside-in damage to the acetabular cartilage; this mechanism may account for many cases previously referred to as idiopathic osteoarthritis.
3. The hip as a fulcrum
   a. The hip functions effectively as a fulcrum, resulting in a state of equilibrium between body weight and the opposing abductor muscles of the hip. To maintain the state of equilibrium, the abductor muscle force must counterbalance the body weight. Because the lever arm between the femoral head and the insertions of the abductor muscles is markedly shorter than

that between the femoral head and the body weight, the abductor muscles must generate markedly larger force. Therefore, the hip joint reaction force is much larger than the body weight.

- The peak contact force in the hip joint during walking is approximately 2.5 times body weight.
- The push-off phase in running generates a joint contact force of approximately 5.2 times body weight.
- The highest calculated forces and torques across the hip joint occur when descending stairs, which may account for the tendency of this motion to cause joint symptoms.

b. Study of the biomechanics of the hip joint during gait has shown that an increase in femoral offset (the perpendicular distance from the center of the femoral head to the anatomic axis of the femur) correlates with a decreased requirement of abductor force to produce a constant net hip moment, thereby decreasing joint reaction forces. A free-body diagram of the hip joint (Figure 1) shows that an increase in femoral offset increases the hip moment. By maintaining a constant hip moment and reducing the femoral offset, the abductor muscle force is reduced, and as a result, the joint reaction forces are reduced as well.

- Restoring femoral offset after hip arthroplasty helps to optimize the function of the abductor muscles by keeping the lever arm of the abductor muscles at the appropriate length, thereby producing the ideal abductor muscle force required for normal gait.
- An excessive reduction of the abductor lever arm (femoral offset) could adversely affect muscle function by decreasing the abductor muscle force.
- A decrease in the abductor muscle force disrupts the joint stability. This triggers a reactive neuromuscular mechanism, thereby increasing the level of muscular cocontraction and increasing the joint reaction forces.

Increasing the joint reaction force at the hip may increase the wear rate of the implant.

C. Polyethylene in THA
   1. Manufacturing—Prosthetic components made of ultra-high-molecular-weight polyethylene (UHMWPE) are most frequentl manufactured by two methods:
      a. Direct molding, in which polyethylene powder is converted by heat and pressure into a final product
      b. Machining bar stock or sheets of polyethylene into the requisite shape
   2. Sterilization
      a. Historically, most prosthetic components composed of UHMWPE were sterilized by gamma irradiation in air, at radiation dose of 2.5 to 4.0 Mrad. This produced free radicals, however, which resulted in oxidative degradation of the polyethylene and associated high wear rates, delamination, and/or gross fracture.
      b. Some polyethylene components were sterilized without radiation, using ethylene oxide or gas plasma. This polyethylene had inferior wear properties, however, because irradiation, despite its drawbacks, induces the cross-linking of polyethylene, which enhances its wear resistance.
   3. Highly cross-linked polyethylene
      a. Currently, polyethylene is sterilized in an inert atmosphere (ethylene oxide or gas plasma) to avoid the introduction of free radicals.

         Either gamma or electron beam radiation, at 5 to 10 Mrad, is now used. This increased level of irradiation has increased the cross-linking of polyethylene (Figure 2) and has therefore improved its wear resistance.

         Remelting or annealing are two processes used to decrease the free radicals created in this optimized process.
      b. Remelting versus annealing—Differentiating remelting from annealing is important. Both processes are currently used by

different manufacturers.

With remelting, the polyethylene is changed from its partial crystalline state to its amorphous state. This can reduce the wear properties of the polyethylene.

With annealing, the polyethylene is heated to a temperature below its melting point, thus avoiding a reduction in its crystallinity but leaving a greater number of free radicals. Concern exists that this process will result in the oxidation of the polyethylene over time.

Current processes used in the manufacture of polyethylene sometimes involve general remelting steps with a final sterilization process in ethylene oxide gas.

c. Second-generation highly cross-linked polyethylenes are now available. These polyethylenes use vitamin E, mechanical deformation, or low doses of radiation alternated with annealing to reduce the production of free radicals.

4. Performance

a. In vitro testing of highly cross-linked polyethylene has shown substantially lower wear rates than those of conventional polyethylene in hip simulator studies.

b. The in vivo performance of cross-linked polyethylene has been very encouraging.

Significant wear reduction (55% to 95% lower than with non–cross-linked polyethylene) has been reported; however, these data were collected in trials that used a variety of polyethylenes, some of which had no cross-linking at all and others that had the standard cross-linking (produced with 2.5 to 4.0 Mrad). This provides some insight into the wide range of relative wear reductions reported with newer methods of making polyethylene.

A polyethylene wear rate of less than 0.1 mm per year is associated with a very low risk of osteolysis. Most currently available implants with polyethylene components have achieved this wear rate.

c. Diminishing material properties with regard to fracture toughness have been an undesirable by-product of the new processes for manufacturing polyethylene. This has been seen with remelting but not annealing.
    - With the remelting process, the final percentage of crystallinity of polyethylene is slightly lower than before remelting. This reduces the fracture toughness/fatigue toughness resistance of polyethylene because crystals arrest crack propagation.
    - Premature failures have occurred in rare instances in which the acetabular implant was placed vertically, with thin polyethylene at its rim. This is especially of concern with implants that have larger femoral head sizes, with a thinner polyethylene acetabular lining.

d. Because of the improved wear resistance of the new polyethylenes, larger femoral head sizes (>32 mm) are currently being implanted.
    - In the past, larger femoral head sizes had been associated with an increased wear rate because of the increased sliding distance of the head across the acetabular surface with each step.
    - At short-term follow-up, the in vivo wear rate with these larger-size heads has been significantly reduced with the newer methods of making polyethylene.

D. Metal-on-metal prostheses

1. Rationale

a. Metal-on-metal articulations produce less volumetric wear than metal-on-polyethylene articulations.

b. This decreased wear may reduce the incidence of osteolysis-induced failure.

c. Enthusiasm for the use of metal-on-metal articulations is tempered by concerns about their generating metal ion debris, as opposed to standard metal-on-polyethylene or ceramic bearing surfaces.

2. Metal-on-metal lubrication theory
    a. The wear characteristics of metal-on-metal prostheses are generally characterized by a run-in wear rate that usually occurs in the first 1 million cycles and is followed by a uniform rate of wear.
    b. The overall volume of wear of metal-on-metal prosthetic joint surfaces has been related to the presence of a minimum elastohydrodynamic fluid film thickness for the mean operating conditions of load, speed, viscosity, and elastic properties of the metals used in each prosthesis, which is described by the lambda ratio.
        The lambda ratio is the ratio of the thickness of the fluid film to the composite root mean square surface roughness.
        If the lambda ratio is 1 or less for a metal-on-metal bearing, severe mixed lubrication conditions occur, which means that abrasive wear occurs by direct contact of the two bearing surfaces. A lambda ratio of 3 or greater, on the other hand, indicates that fluid film lubrication is sufficient to substantially reduce the effect of load and hence minimize friction and wear.
        Lower clearance and larger femoral head sizes promote higher lambda ratios.
    c. Clearance is another factor that influences wear in metal-on-metal bearings.
        In THA, clearance is the difference between the diameter o the femoral head and the diameter of the acetabular cup, with clearances of 100 to 200 μm maximizing the fluid film thickness. These clearances maximize joint fluid entrapment between the two bearing surfaces.
        Clearances that are too high result in increased wear, and clearances that are too low can result in clamping and/or equatorial seizing.
    d. A larger femoral head diameter increases the entrainment velocity (ie, the speed with which the fluid is brought into the

joint), maximizing fluid film lubrication. Even with an ideal head diameter and clearance, mixed film lubrication probably occurs most frequently in vivo.

e. Contact patch to rim (CPR) distance

CPR distance is the distance between the point of application of the joint reaction force and the rim of the acetabular implant in a patient in the standing position.

An inverse relationship exists between wear and CPR distance.

The mean CPR distance is approximately 14 mm.

A CPR distance of less than 5 mm is associated with increased metal ion levels and increased rates of prosthetic loosening, wear, and dislocation.

Factors that result in decreased CPR distance include a high abduction angle of the acetabular implant, excessive anteversion of the acetabular cup, and cup designs with smaller arcs of coverage of the femoral head.

3. In vivo results

a. Early in vivo data from the analysis of retrieved McKee–Farrar prostheses show mean linear wear rates of 0.003 and 0.004 mm/yr for the femoral head and cup, respectively. Larger diameter (42 mm) femoral heads had a twofold lower mean volumetric wear rate than did smaller diameter (35 mm) femoral heads (0.7 versus 1.4 mm^3 per year, respectively).

b. Current-generation metal-on-metal bearings (high-carbon, wrought cobalt-chromium alloy) with a 28-mm-diameter femoral head had a mean in vivo wear rate of 27.8 μm/yr for the first year of use and 6.2 μm/yr after the second year, with femoral heads generally exhibiting a higher wear rate than acetabular cups. A positive correlation between clearance and wear rate was also seen.

c. Metal-on-metal bearings and corresponding metallic wear debris can release metallic ions in substantially greater concentrations than typically occurs with polyethylene-covered

or ceramic bearings, and these ions may form soluble or precipitated organometallic substances.

- Metal-on-metal wear debris particles are approximately 10 to 50 nm.
- Corrosion, both mechanical and chemical, of the articular surfaces of a metal-on-metal joint prosthesis leads to the production of metal ions (eg, Co^{2+}), which are measured in the tissues, blood, and urine. The concentrations of these ions are currently being measured prospectively with both resurfacing and stem-type hip devices and have been found to be increased in all series in which they have been measured.

4. Drawbacks of metal bearings
   a. Recently, two types of adverse reactions have been noted in failed metal-on-metal THAs that produced osteolytic responses with persistent pain, the frequency of which is not known.
      - One such adverse reaction is a perivascular infiltrate of lymphocytes indicative of a delayed-type hypersensitivity (DTH) response to metal wear products, with the development of a typical immunologic response.
      - Other authors have noted the presence of plasma cells, B lymphocytes, and massive fibrin exudation not characteristic of a type IV DTH reaction and described a an aseptic, lymphocyte-dominated, vasculitis-associated lesion (ALVAL), or as a lymphocyte-dominated immunologic answer (LYDIA).
      - Pseudotumors or adverse local tissue reactions have been described after metal-on-metal hip resurfacing as well as with THAs that have a large femoral head, with a substantially higher incidence in the latter group. The histopathology of several retrieved pseudotumors has been consistent with ALVAL combined with substantial tissue necrosis. Pseudotumor has been reported in both painful and well-functioning prostheses, however, and the

degree of implant wear has not yet been directly correlated with the severity of adverse local tissue reactions.

b. Metal wear particles generated by metal-on-metal hip arthroplasty may have cytotoxic effects as a result of the dispersal of these particles throughout the body.

An early review of the incidence of cancer in patients with prostheses with metal-on-metal bearings found that leukemia was the only cancer that could potentially occur at an increased rate in these patients. The follow-up period was only 5 to 14 years, however, and the longer follow-up times did not show any increased risk of hematopoietic cancers.

More recent, large population-based studies have shown no greater risk of hematopoietic or other cancers at 7-year follow-up.

Importantly, a 20-year follow-up study of THA patients dic not show a difference in mortality rate between patients with metal-on-metal hips and those with metal-polyethylene hips.

E. Ceramic bearings

1. Material properties

a. Alumina

The alumina used in modern arthroplasty, Al_2O_3, is a dense, polycrystalline ceramic obtained from aluminum oxide powder and pressed in a mold at a very high temperature.

Al_2O_3 is very stable and chemically inert.

Although alumina is very resistant to compression, it is brittle and susceptible to fracture.

Recent analysis of clinical data suggests a fracture rate of approximately 0.012% for alumina femoral heads and inserts in THAs.

b. Zirconia

To minimize the risk of fracture associated with alumina, zirconia was introduced as an alternative ceramic for the

components of prosthetic joints.

Unlike alumina, zirconia needs to be chemically stabilized.

Zirconia exists in three distinct crystalline phases—monoclinic, tetragonal, and cubic. The phase changes result in a greater variation in volume than occurs in alumina and reduce its mechanical durability substantially because of the occurrence of cracks. To maintain zirconia in its most stable, tetragonal phase, yttrium oxides have been added to bond with the zirconia, creating yttrium-stabilized tetragonal polycrystalline zirconia.

Unfortunately, the clinical wear of zirconia on polyethylene has been found to be greater in vivo than what was predicted in vitro, averaging 0.17 mm/yr. This is substantially greater than the wear of alumina on polyethylene, which averages 0.07 mm/yr. As such, pure zirconia implants are no longer used in THA.

c. Fourth-generation ceramic bearings—zirconia-toughened alumina (ZTA)

Production involves homogeneous distribution of yttria-stabilized tetragonal zirconia particles (24%) and strontium oxide to alumina (75%) to prevent crack propagation. This theoretically maintains the wear properties of alumina while decreasing the risk of fracture.

An in vitro study showed 6 to 12 times lower wear rates compared with alumina bearings.

Registry data show no significant difference in revision rate up to 7 years when compared with metal on cross linked polyethylene (XLPE).

d. Oxidized zirconia

This is produced through a process of thermally treating zirconium metal and niobium to create a hard, smooth ceramic outer core. The rest of the implant remains metal, thereby theoretically decreasing fracture risk.

Midterm in vivo wear studies comparing this to ceramic and

CoCr femoral heads has been variable.

2. Wear rates
    a. Alumina is a wettable material. Clearances of 20 to 50 μm should be achieved during the manufacturing process to provide optimal fluid film lubrication.
    b. As with metal-on-metal bearings, the alumina/alumina couple exhibits biphasic behavior, with run-in and steady state wear rates of 1.2 and 0.02 mm^3 per million cycles, respectively.
        Generally, a reduction in grain size and porosity of the alumina correlates with a lower wear rate.
        Of recent concern is the phenomenon of microseparation, leading to stripe wear. This is usually present on the femoral head, where it potentially edge loads with the acetabulum during rising from a seated to standing position.
        Wear rates in THAs with stripe wear can be up to 0.3 mm/yr or 1.24 mm^3 per million cycles.
        Recent analysis of alumina wear debris has shown that it has a bimodal distribution, with particle sizes of 5 to 90 nm and 0.05 to 3.2 μm. The latter are thought to be the result of microseparation of the surface of the acetabulum from that of the femoral head.
    c. Generally, the periprosthetic tissues in failed ceramic-on-ceramic prostheses have been found to have thinner synovial layers, fewer macrophages, and lower production of osteolytic substances than metal-on-polyethylene articular surfaces.
3. Drawbacks of ceramic bearings
    a. Revision of ceramic prostheses after catastrophic fracture of a ceramic femoral head or acetabular liner remains a difficult problem, with some authors reporting a prosthetic survival rate of only 63% at 5 years, due to aseptic loosening and osteolysis.
    b. Risk factors for head fracture include a small femoral head (28 mm) and a short neck size. Risk factors for liner fracture

include cup malposition (excessive anteversion) and malalignment of liner during insertion. Obesity is a risk factor for both.

c. Revision for a fractured ceramic bearing must include a complete synovectomy to remove remnant ceramic particles that can cause third body wear. Revision of the acetabular implant is necessary if there is damage to the locking mechanism or component malposition. If there is minimal damage to the femoral taper, the femoral stem may be retained and revised with a fourth-generation ceramic head with a titanium sleeve. If there is damage beyond simple scratches or corrosion, revision of the femoral implant is necessary.

d. During revision for a fractured ceramic femoral head or liner, a ceramic-on-ceramic or ceramic-on-polyethylene bearing should be used. Metal-on-polyethylene bearings should be avoided to prevent third-body wear and head erosion.

F. Femoral head-neck modularity and corrosion

1. Rationale

a. Head-neck modularity of the femoral implant of a THA allows intraoperative flexibility to address patients' leg lengths and, to a lesser degree, head-neck offset. It also facilitates exchange of the femoral head in the setting of revision arthroplasty.

b. Modularity typically occurs at a Morse taper. As it expands, the male portion of the taper (trunnion) compresses the female portion (the bore in the femoral head), interlocking the two components in both an axial and rotational direction.

c. The drawback of modularity is that each additional interface in a prosthesis increases the number of potential areas of failure.

d. Modular components can form a protective surface oxide layer (self-passivation) that resists corrosion. Mismatch between two metal components and micromotion can lead to repeated disruption of this layer, however, making it susceptible to corrosion.

e. Corrosion at the femoral head-neck taper (trunnionosis) has

been identified as an important source of metal ion release and pseudotumor formation requiring revision surgery. This process appears to be similar to adverse metal tissue reactions secondary to metal-on-metal bearing surfaces.

2. Three types of corrosion occur at the head-neck taper of a THA.
    a. Crevice corrosion—The presence of small gaps allows fluid to enter and create crevice corrosion at the Morse taper. The incidence of crevice corrosion in retrieval studies is 35% to 40% with mixed-metal tapers and 9% to 28% with single-alloy components. This is thought to be the dominant type in trunnionosis.
    b. Fretting corrosion—This is typically caused by micromotion at the femoral head-neck interface. Reports suggest that less fretting may occur when a ceramic head is mated to a cobalt-chromium trunnion.
    c. Galvanic corrosion—This occurs in the presence of fluid when there is a metal alloy mismatch. This type of corrosion is most commonly seen when a titanium trunnion is mated to a cobalt-chromium head.
3. Risk factors
    a. Larger femoral head sizes, smaller diameter and shorter tapers, longer neck length, lower flexural rigidity, and dissimilar alloy pairings have been shown to increase risk of trunnionosis. Patient factors include higher body mass index (BMI), longer implantation time, and activity level.
4. Diagnosis
    a. Diagnosis of head-neck junction corrosion can be quite difficult. Clinical presentation can vary and includes no symptoms, pain, palpable masses, limp secondary to abductor damage, late recurrent instability, and catastrophic implant failures.
    b. Cross-sectional imaging such as ultrasound or metal-artifact reduction MRI is essential in the workup.
    c. Workup should include an evaluation for infection with a

manual cell count to avoid a false-positive interpretation due to cellular and metal debris.

d. Serum metal ion levels should also be obtained. A greater degree of elevation of cobalt versus chromium levels (>5:1) suggests trunnionosis.

5. Treatment
   a. A complete synovectomy is necessary to remove nonviable tissue and reduce further corrosion.
   b. Femoral head exchange (either sleeved ceramic or metal) with retention of a well-fixed stem has shown good short-term outcomes. A ceramic head may theoretically reduce recurrence of corrosion and adverse local tissue reaction.
6. Fatigue fracture of the femoral neck
   a. Fatigue fracture of the femoral neck in nonmodular femoral implant is a rare complication, caused by repetitive cycling of the femoral implant.
   b. Risk factors include increased femoral neck length and patient obesity.
   c. Large-diameter tapers (14/16) offer increased resistance against fatigue fracture but may be associated with higher rates of dislocation because impingement between the neck and acetabular implant occurs earlier in the arc of motion than occurs with smaller diameter tapers (12/14).

G. Other sites of modularity in THAs
   1. A modular neck-stem junction is another possible source of corrosion. A retrieval analysis identified head-neck corrosion in 54% of metal-on-metal femoral components and neck-stem corrosion in 88%.
   2. Metaphyseal neck-stem modularity in a THA may also be a site o corrosion, although reported failures from corrosion at this site are rare.

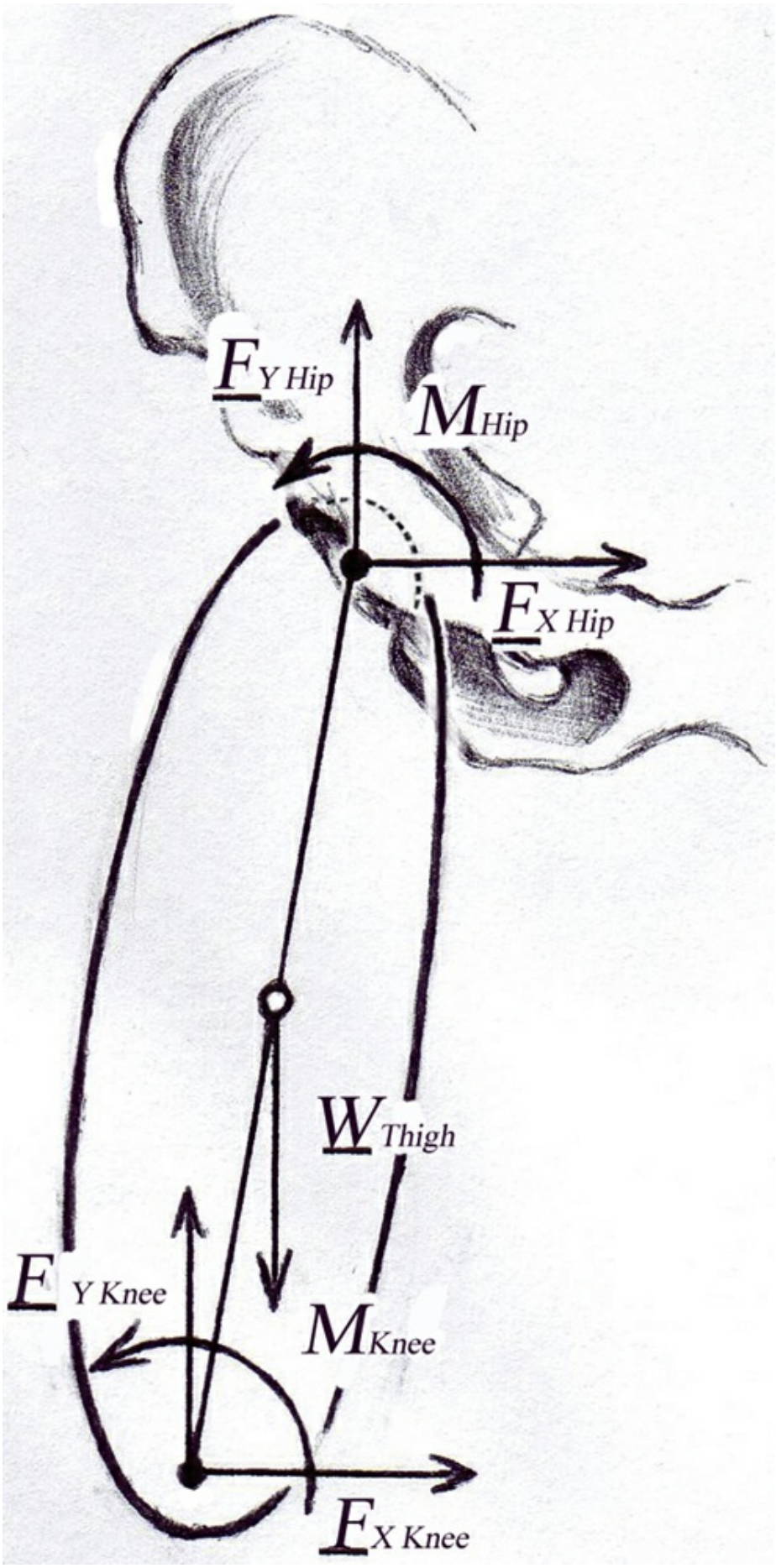
$F_{Y\,Hip}$
M_{Hip}
$F_{X\,Hip}$
W_{Thigh}
$E_{Y\,Knee}$
M_{Knee}
$E_{X\,Knee}$

FIGURE 1 Free-body diagram of the hip joint. FO = femoral offset, FX Hip = net hip force in the X direction, FX Knee = net knee force in the X direction, FY Hip = net hip force in the Y direction, FY Knee = net knee force in the Y direction, G = gravity force vector, MZ Hip = net hip moment of force about the Z axis, MZ Knee = net knee moment of force about the Z axis, W Thigh = total thigh weight vector from the thigh segment center of mass.

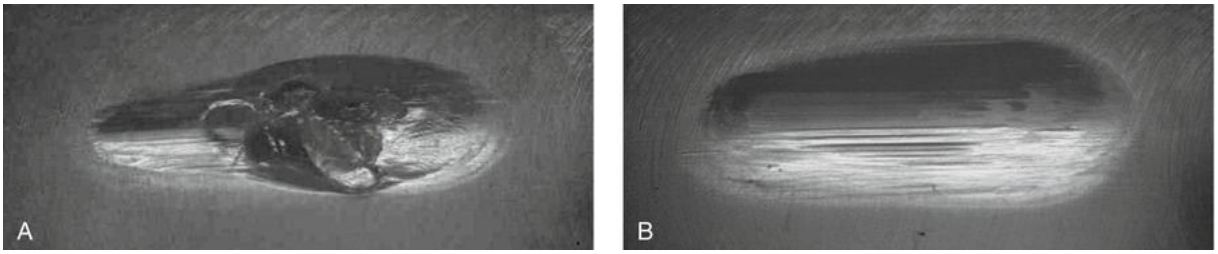

FIGURE 2 Scanning electron microscopic image demonstrates wear tracks in two different materials after testing on a knee-like wear apparatus for 2 million cycles under identical conditions. **A,** Conventional polyethylene (1,050 resin irradiated at 25 kGy). **B,** Highly cross-linked polyethylene (1,050 resin irradiated at 65 kGy). The conventional material shows more severe damage. The elastic moduli were 1.0 GPa for the conventional material and 800 MPa for the highly cross-linked material.(Reproduced with permission from FurmanBD , MaherSA , MorganT , WrightTM : Elevated crosslinking alone does not explain polyethylene wear resistance, in: KurtzSM , GsellR , MartellJ , eds: Crosslinked and Thermally Treated Ultra-High Molecular Weight Polyethylene for Joint Arthroplasties . ASTM STP 1445. West Conshohocken, PA, ASTM International, 2004, pp 248-261.)

III. The Knee Joint

A. Kinematics
   1. Kinematics of the knee joint describes motion in the sagittal, transverse, and frontal planes.
      a. The greatest ROM occurs in the sagittal plane (approximately 160°).
      b. Motion in the transverse and frontal planes is linked to the position of the joint in the sagittal plane. The ROM increases as knee flexion increases, reaching a maximum at 90° of flexion.
   2. Knee rotation ranges from 45° in external rotation to 30° in internal rotation.

3. In the frontal plane, the ROM in both abduction and adduction reaches a maximum of 10°.
4. Knee ROM in the sagittal, frontal, and transverse planes during walking reaches approximately 70°, 15°, and 10°, respectively.
5. More extreme motion, such as squatting, requires knee flexion of up to 160° and external rotation of up to 20°.

B. Biomechanics
1. The normal instant center of the knee joint follows a semicircular path, which is related to the tibiofemoral surface and ligaments crossing the joint.
    a. The motion of the joint surface occurs between the tibial and femoral condyles and between the femoral condyles and the patella.
    b. Studies show that rupture of the cruciate ligaments or disruption of the tibiofemoral surface, including the menisci, causes a major change in the path of the instant center, leading to articular dysfunction.
2. The slip velocity between the condyle and tibial plateau of a TKA can quantify the degree of rolling and sliding of the tibiofemoral joint surfaces across one another. During walking, high slip velocities at heel strike indicate the potential for a magnitude of sliding motion that can increase the volume of abrasive wear debris.
3. Successful TKA relies on proper positioning of the components to restore the mechanical axis of the lower extremity.
4. Gait studies have shown that correcting a varus deformity of the knee to restore normal alignment after TKA can reduce asymmetric muscle contraction patterns and joint loading, and that this can also reduce the risk of tibial component loosening.

C. Polyethylene in TKA
1. Wear
    a. The wear of polyethylene in TKA is of multifactorial origin and has a varied presentation.
    b. It can be divided into three categories: delamination, abrasive wear, and adhesive wear.

Delamination refers to the formation of subsurface cracks in the polyethylene, which propagate to the surface over time.

Abrasive and adhesive wear refers to debris formed through micromotion between the polyethylene and the metallic components of the prosthesis. This can occur between the undersurface of the polyethylene liner and the tibial baseplate of a TKA and/or between the polyethylene post and the femoral box in prostheses with a posterior cruciate–substituting design.

c. The generation of polyethylene wear particles initiates an inflammatory process that results in bone resorption and aseptic loosening. The polyethylene debris is phagocytosed by macrophages from the surrounding tissue, inducing these cells to release cytokines that upregulate the production and function of osteoclasts and initiate bone resorption.

d. Research has focused on identifying risk factors for polyethylene wear. The type of polyethylene resin, initial processing, sterilization, and packaging have all been identified as independent factors in the production of polyethylene wear debris.

e. Retrieval analysis has been the traditional means of measuring wear rates. Recently, radiostereometric analysis has been used to quantify wear in vivo; such analysis of TKAs with polyethylene components has reported wear rates of 0.13 mm/yr.

2. Sterilization—See Section II.C.2 for a discussion of polyethylen sterilization.

3. Processing

a. Compression molding involves the application of heat and pressure to raw polyethylene resin to produce the finished articular surface. No additional finishing or machining is done.

b. Ram extrusion or machining produces sheets of polyethylene that are then shaped or machined to the final product.

c. Biomechanical studies have shown that compression molding

and ram extrusion are associated with similar rates of polyethylene wear; however, compression-molded polyethylene has a lower susceptibility to fatigue cracking and crack propagation.

d. In vitro knee simulator studies have shown improved resistance to adhesive and abrasive wear and delamination with highly cross-linked polyethylene.

4. Shelf age and polyethylene thickness
   a. Shelf age
      Studies have shown a direct correlation between the age of a polyethylene insert and the generation of wear debris.
      As previously mentioned, the storage of polyethylene in air after gamma irradiation allows the generation of free radicals, which bond to the polyethylene.
      Exposure to oxygen on the shelf or after implantation can lead to the bonding of oxygen free radicals to polyethylene, decreasing its mechanical properties.
   b. Thickness
      An insert thickness of less than 6 mm results in increased wear rates.
      A minimum polyethylene thickness of 6 to 8 mm is currently recommended.
5. Polyethylene wear and osteolysis
   a. Polyethylene wear is the main cause of osteolysis.
   b. The emergence of osteolysis as a substantial problem in TKA corresponded to the change in design of prosthetic knee joints from those with all-polyethylene tibial components to those with modular components that include a metal tibial tray.
      Current TKAs use a modular tibial component.
      Locking mechanisms have been implicated in the production of polyethylene wear debris as a result of micromotion between the tibial tray and a polyethylene insert.
      The term “backside wear” refers to the generation of polyethylene debris by micromotion between the

undersurface of the polyethylene insert and the tibial baseplate.

Earlier prosthetic designs with modular tibial components had tibial trays with a rough finish. This has been shown to increase abrasive wear and the production of polyethylene debris.

c. Cam-post impingement has been implicated as a source of polyethylene debris in TKAs with a posterior cruciate-substituting design. Some authors have suggested that rotational forces are transmitted from the cam-post interface to the tibial tray, increasing backside wear in such prostheses. However, clinical studies have not consistently shown differences in revision, osteolysis, loosening, or functional outcomes for cruciate-retaining versus cruciate-substituting TKA designs.

6. Design issues (Table 1)
   a. Improvements have been made in locking mechanisms between the tibial trays and polyethylene liners of TKA designs in an attempt to limit backside wear.
   b. Contemporary designs also have an improved tibial baseplate finish to limit abrasive and adhesive wear.
   c. Mobile-bearing designs have been introduced in an attempt to decouple rotation and glide to reduce the stress on polyethylene at the tibiofemoral interface.

TABLE 1
Characteristics of Total Knee Arthroplasty Designs

Design Type	Constraint Type	Bone Resection	Range of Motion	Backside Wear	Complications
Posterior ◎cruciate–retaining	Unconstrained	Spares femoral bone	Normal	Evident	Late posterior cruciate insufficiency
Posterior ◎cruciate–substituting	Unconstrained	Femoral box resection	Increased flexion	Evident	Patellar clunk syndrome Post

					impingement
Mobile bearing	Unconstrained	Sparing	Normal	Minimized	Dislocation of mobile bearing
Varus-valgus constrained	Constrained	Large femoral box resection	Normal	Evident	Post impingement
Rotating hinge	Highly constrained	Large femoral box resection	Normal	Evident	Mechanical failure of hinge

Top Testing Facts

1. Adhesive wear predominates in metal-on-polyethylene bearings in THA.
2. Gait biomechanics show that an increase in femoral offset (perpendicular distance from the center of the femoral head to the anatomic axis of the femur) correlates with a decrease in abductor force requirements for a constant net hip movement, consequently decreasing joint reaction forces.
3. The level of radiation exposure has the greatest influence on the wear properties of polyethylene.
4. Increasing the level of polyethylene irradiation has resulted in greater cross-linking and improved resistance. Remelting or annealing decreases free radicals from polyethylene.
5. Diametral clearance, carbon content, and the CPR distance are the main determinants of wear in metal-on-metal bearings.
6. Alumina is the most stable ceramic bearing surface in vivo; zirconia demonstrates a tendency to switch from its stable tetragonal phase to its monoclinic phase in vivo.
7. Modular junctions in a THA (head-neck and neck-stem) can be substantial sources of metallic wear debris through corrosion, resulting in adverse local tissue reactions.
8. Metal particles tend to produce diffuse and perivascular infiltrates of T and B lymphocytes and plasma cells, ALVAL lesions, massive fibrin exudation, accumulation of macrophages, delayed-type hypersensitivity reactions, infiltrates of eosinophilic granulocytes, and necrosis.
9. Hip revision after the catastrophic failure of a ceramic femoral head has a low survival rate at midterm follow-up because of aseptic loosening and osteolysis.
10. Backside wear and tibial post impingement are two common sources of wear debris in TKA not usually found in THA.

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CHAPTER 52

Periprosthetic Joint Infections

ERIK N. HANSEN MD

JAVAD PARVIZI MD, FRCS

I. Epidemiology and Overview

A. Prevalence
   1. The risk of periprosthetic joint infection (PJI) following primary knee arthroplasty (1% to 2%) is slightly higher than that following hip arthroplasty (0.3% to 1.3%).
   2. The risk of infection is higher after revision procedures: 3% for hips and 6% for knees.

B. Risk factors (see risk calculator on ICMPhilly App)
   1. Postoperative wound complications such as hematoma formation, persistent drainage, dehiscence, or surgical site infection
   2. Immunocompromised status such as history of malignancy, uncontrolled diabetes, inflammatory conditions, or being on immune-modulating agents
   3. Prior surgery in the affected joint, such as arthroscopy or arthroplasty
   4. Prior history of infection in the joint or adjacent bone
   5. Perioperative nonarticular infection
   6. Potent or excessive anticoagulation (such as coumadin, low-molecular-weight heparin or factor X inhibitors)

C. Prophylaxis—Optimization of the patient and addressing modifiable risk factors is critical for prevention of infection. Timely (within 30 minutes) and weight-based administration of effective antibiotics (eg, cephalosporin) is also critical for prevention of infection.

D. Classification—A classification of infected total joint arthroplasty is outlined in Table 1.

TABLE 1

Classification of Periprosthetic Joint Infections

Type	Presentation	Definition	Treatment
I	Acute postoperative infection	Acute infection within first month	Attempted débridement and prosthetic retention
II	Late chronic infection	Chronic indolent infection presenting >1 mo after surgery	Prosthetic removal
III	Acute hematogenous infection	Acute onset of symptoms in a previously well-functioning joint	Attempted débridement and prosthetic retention, or prosthetic removal
IV	Positive intraoperative cultures	Two or more positive intraoperative cultures	Appropriate antibiotics

II. Presentation and Etiology

A. General symptoms
   1. Pain at the implant site is the most common symptom of PJI.
   2. Pain at the implant site is associated with infection in more than 90% of patients.

B. Typical patient presentations and etiologies for several types of PJIs are listed in Table 2.

TABLE 2

Etiologies, Signs, and Symptoms of Periprosthetic Joint Infections

Type of Infection	Etiology	Time of Onset	Signs and

			Symptoms
Acute postoperative infection	Frequently caused by *Staphylococcus aureus*, β-hemolytic *Streptococcus*, and sometimes by gram-negative bacteria	Symptoms appear within days to weeks	Acute onset of joint pain and swelling together with erythema, warmth, tenderness, and possible wound discharge Sinus tract extending to the joint is a definitive sign of infection
Late chronic infection	Frequently caused by less-virulent organisms: coagulase-negative staphylococci and *Propionibacterium acnes*	Occurs several months to 2 yr after prosthesis implantation	Subtle signs and symptoms, if any chronic pain and implant loosening are common Difficult to differentiate from mechanical aseptic loosening, but pain associated with chronic infection worsens with time and is accompanied by deterioration in function
Hematogenous seeding	Inciting events: Skin infection, dental extraction, respiratory tract infection, urinary tract infection	Within days after inciting event	Sudden onset of pain

III. Definition

A. Although the prior Musculoskeletal Infection Society (MSIS) an International Consensus Meeting (ICM) definitions helped standardiz PJI diagnosis for patients and clinicians, these recommendations were generated largely through expert opinion (Table 3). Earlier this year, a multi-institutional effort developed a new PJI diagnostic scoring system (Table 4), which shows improved diagnostic performance and formal external validation versus the current ICM and MSIS definitions. Thi updated schema also incorporates newer diagnostic biomarkers and molecular tests, which were not considered in the prior definition (see ICMPhilly App).

TABLE 3

The Musculoskeletal Infection Society Definition for PJI

Definition of Periprosthetic Joint Infection according to the International Consensus Group. This is an adaptation of the Musculoskeletal Infection Society definition of PJI.		
PJI is present when one of the major criteria exists or three out of five minor criteria exist		
Major criteria	Two positive periprosthetic cultures with phenotypically identical organisms, **OR** A sinus tract communicating with the joint, **OR**	
Minor criteria	1. Elevated serum C-reactive protein (CRP) **AND** erythrocyte sedimentation rate (ESR) 2. Elevated synovial fluid white blood cell (WBC) count **OR** ++ change on leukocyte esterase test strip 3. Elevated synovial fluid polymorphonuclear neutrophil percentage (PMN %) 4. Positive histological analysis of periprosthetic tissue 5. A single positive culture	
Declaration: The consensus group wishes to state that PJI may be present without meeting these criteria, specifically in the case of less virulent organisms (eg, *Propionibacterium acnes*). Thus, the clinicians are urged to exercise their judgment and clinical acumen in reaching the diagnosis of PJI.		
The Threshold for the Minor Diagnostic Criteria		
Criterion	**Acute PJI (<90 d)**	**Chronic PJI (>90 d)**
Erythrocyte sedimentation rate (mm/hr)	Not helpful. No threshold was determined	30

C-reactive protein (mg/L)	100	10
Synovia white blood cell count (cells/μL)	10,000	3,000
Synovial polymorphonuclear (%)	90	80
Leukocyte esterase	+ Or ++	+ Or ++
Histological analysis of tissue	>5 neutrophils per high power field in 5 high power fields (× 400)	Same as acute

(Reproduced with permission from ParviziJ , GehrkeT . Definition of periprosthetic joint infection. *J Arthroplasty* 2014;29(7):1331. doi:10.1016/j.arth.2014.03.009.)

TABLE 4

The 2018 Validated and Score-based Definition for PJI

Major criteria (at least one of the following)				**Decision**
Two positive cultures of the same organism				Infected
Sinus tract with evidence of communication to the joint or visualization of the prosthesis				
Preoperative diagnosis	**Minor criteria**		**Score**	**Decision**
	Serum	Elevated CRP *or* D-Dimer	2	≥6: Infected 2-5: Possibly infected [a] 0-1: Not infected
		Elevated ESR	1	
	Synovial	Elevated synovial *WBC or LE* (++)	3	
		Positive alpha-defensin	3	
		Elevated synovial PMN %	2	
		Elevated synovial CRP	1	
Postoperative diagnosis		**Inconclusive pre-op score** *or* **dry tap** [a]	**Score**	**Decision**
		Preoperative score	—	≥6: Infected **4-5: Inconclusive** [b] ≤3: NNot infected
		Positive histology	3	
		Positive purulence	3	
		Positive single culture	2	

Reproduced with permission from ParviziJ , TanTL , GoswamiK , et al: The 2018 definition of periprosthetic hip and knee infection: An evidence-based and validated criteria. *J Arthroplasty* 2018;33(5):1309-1314, e2. doi:10.1016/j.arth.2018.02.078.

For patients with inconclusive minor criteria, operative criteria can also be used to fulfill definition for PJI.

Consider further molecular diagnostics such as next-generation sequencing.

Proceed with caution in: adverse local tissue reaction, crystal deposition disease, slow-growing organisms.

IV. Diagnosis

A. History and physical examination
   1. A detailed history and physical examination can diagnose PJI with reasonable certainty; laboratory tests simply confirm the diagnosis.
   2. Frequently, signs and symptoms of PJI overlap those of hematoma formation, aseptic prosthetic loosening, or prosthetic instability, thus necessitating additional diagnostic tests.

B. Imaging studies
   1. Radiographic signs of PJI (Figure 1)
      a. Periosteal reaction
      b. Scattered foci of osteolysis
      c. Generalized bone resorption in the absence of implant wear
   2. Radionuclide studies
      a. When infection is clinically suspected but cannot be confirmed by repeat aspiration, bone scanning may be indicated.
      b. Radionuclide studies have a high sensitivity of 99% for PJI but suffer a low specificity of 30% to 40%.
      c. Technetium Tc-99m detects inflammation, and indium In-111 detects leukocytes in periprosthetic tissue.
      d. A triple scan can distinguish infection from conditions with high metabolic activity, such as fracture or bone remodeling, improving the specificity of PJI diagnosis to 95%.
   3. Positron emission tomography (PET)
      a. PET has recently been shown to have a role in the diagnosis of PJI, with sensitivity of 98% and specificity of 98%.
      b. PET scanning can be performed with fluorinated deoxyglucose (FDG-PET), which travels to areas of high metabolic activity.

C. Serologic tests
   1. The erythrocyte sedimentation rate (ESR) and serum C-reactive protein (CRP) concentration are nonspecific markers of inflammation that, in combination, are very useful as an initial

screening tool in the diagnosis of infection.

a. Although combined ESR (>30) and CRP (>10 mg/L) has bee traditionally believed to carry a high sensitivity, recent studies demonstrate that ESR and CRP may be normal in a group c patients with PJI caused by indolent organisms. Thus, othe serum tests have been explored recently (see below).
b. The CRP level normalizes within 21 days following surgery whereas the ESR may require up to 90 days to normalize.
c. Continued high levels of CRP and ESR should elicit concer about possible infection.

2. Interleukin-6 (IL-6) is a cytokine produced by activated monocytes and macrophages as part of the inflammatory response.
   a. IL-6 may be a faster and more sensitive marker for detection of PJI because it lies upstream of other markers in the acute phase inflammatory cascade.
   b. IL-6 serum levels return to normal (<1 pg/mL) within approximately 2 to 3 days of uncomplicated arthroplasty.
   c. Because of wide variation in levels with an unknown threshold, lack of easy accessibility, and cost, IL-6 has not yet gained widespread adoption.
3. D-dimer is a fibrin degradation product released in blood following fibrin clot breakdown by plasmin.
   a. Although a nonspecific marker that aids in screening for venous thromboembolism, it has shown promise as a biomarker for diagnosis of PJI and determining optimal time for reimplantation in two-stage exchange arthroplasty.
   b. A threshold of 850 ng/mL was chosen as optimal cutoff value for PJI diagnosis.

D. Joint aspiration

1. Joint fluid aspiration is performed when infection is strongly suspected.
2. Aspiration has sensitivity of 57% to 93% and specificity of 88% to 100%. The sensitivity can be improved by repeat aspiration.
3. For the acute period (<6 weeks postoperatively) a threshold of

10,000 WBC/μL as well as >90% (polymorphonuclear neutrophils PMNs is recommended to diagnose PJI. For the chroni postoperative period (>6 weeks), a threshold of >3,000 WBC/μL anc >80% PMNs is recommended.

4. False-negative results can be caused by improper technique, low-virulence or biofilm-producing organisms, or antibiotic therapy at the time of aspiration.
5. False-positive results may be caused by contamination, which can be avoided with a more sterile technique. Additionally, a false-positive result may be seen in cases of adverse local tissue reactions, as a result of monocyte-phagocytosed metal particles interfering with laboratory instruments, and in these settings a manual synovial WBC count is recommended.
6. The leukocyte esterase colorimetric chemical strip, previously used to diagnose urinary tract infection, is a low-cost, semiquantitative, point-of-service test that is 81% sensitive and 100% specific for the diagnosis of PJI, with a positive predictive value of 100% and negative predictive value of 93%.
7. Alpha defensin is a naturally occurring antimicrobial peptide released from activated neutrophils as part of the innate immune response to pathogens.
    a. It has shown to rise in response to low-virulence organisms and is unaffected by prior antibiotic administration.
    b. A meta-analysis demonstrated excellent diagnostic characteristics with a pooled sensitivity of 100% with specificity of 96%.
    c. Similar to synovial WBC count, adverse reaction to metallic debris may confound interpretation of alpha defensin results.

E. Microbiology

1. A definitive diagnosis can be made when the same pathogen is recovered either from serial joint aspiration or from at least two of three specimens of periprosthetic tissue obtained at surgery.
2. The false-positive rate is not known with certainty, but may be approximately 8%.

3. With the increase in numbers of biofilm-producing and slow-growing, fastidious organisms (eg, *Propionibacterium acnes*), techniques for improving the accuracy of diagnosis of PJI include keeping cultures for a minimum of 14 days and using enriched media for the culture of aspirate and tissue specimens.

F. Histopathology

1. Gram staining has an unacceptable level of sensitivity (0% to 23%) for PJI and is therefore considered unreliable for its diagnosis (ie, a negative Gram stain means little, whereas a positive Gram stain is almost definitive for infection).
2. Frozen sections
    a. Frozen sections are another valuable tool for the diagnosis of PJI.
    b. They are most useful in equivocal cases in which preoperative investigations are confounded by false increases in the ESR and CRP concentration or when the intraoperative appearance of the joint may indicate infection.
    c. Most studies with frozen sections report favorable results, with sensitivity approaching 85% and specificity of approximately 90% to 95%.
    d. Current definition of positive histologic analysis of periprosthetic tissue—"acute inflammation": >5 neutrophils/high power field (HPF) in 5 HPF (at 400 magnification)

G. Molecular techniques

1. Conventional polymerase chain reaction (PCR) of joint fluid aspirate
    a. This technique relies on amplification of bacterial DNA.
    b. The test is so sensitive that contamination with a few bacteria may yield a false-positive result.
    c. The test amplifies dead as well as live bacteria.
2. Custom PCR
    a. Selective amplification of regions of DNA or ribosomal RNA
    b. Multiplex PCR, with pangenomic amplification of DNA an

mass spectrometry, has improved the accuracy of PCR for the diagnosis of PJI.

c. Multiplex PCR was used occasionally for identification of pathogenic bacteria in patients with culture-negative PJI. This has been replaced mostly by next-generation sequencing (NGS) (see below)

3. Microarray technology
   a. Microarray technology attempts to target specific bacterial genes.
   b. It produces a profile of the genes (microarray) present in the joint aspirate or periarticular tissues and relies on identifying signature genes/proteins that indicate infection.
   c. This technology is not commonly used in clinical practice because of its variability and lack of reliability.
4. Multiplex enzyme-linked immunosorbent assay
   a. The identification and quantification of proteins present in a joint aspirate has great promise for the development of biomarkers of infection in orthopaedics, even when patients with systemic inflammatory disease and those receiving antibiotic treatment are included. Five biomarkers, including human alpha defensin 1 to 3, neutrophil elastase 2, bactericidal/permeability-increasing protein, neutrophil gelatinase-associated lipocalin, and lactoferrin, correctly predicted the Musculoskeletal Information Society classification with 100% sensitivity and specificity.
   b. Enzyme-linked immunosorbent assay is simple to perform and has much greater accuracy than gene amplification (PCR or microarray technology)
5. Next-generation sequencing
   a. High-throughput DNA sequencing. Unlike PCR, NGS can be used in "open" mode, which does not rely on a set of parameters or a panel of primer targets.
   b. Searches all microbial databases, including bacteria, viruses, yeast, fungi and parasites

c. Has ability to detect antimicrobial resistance through identification of known resistance genes.

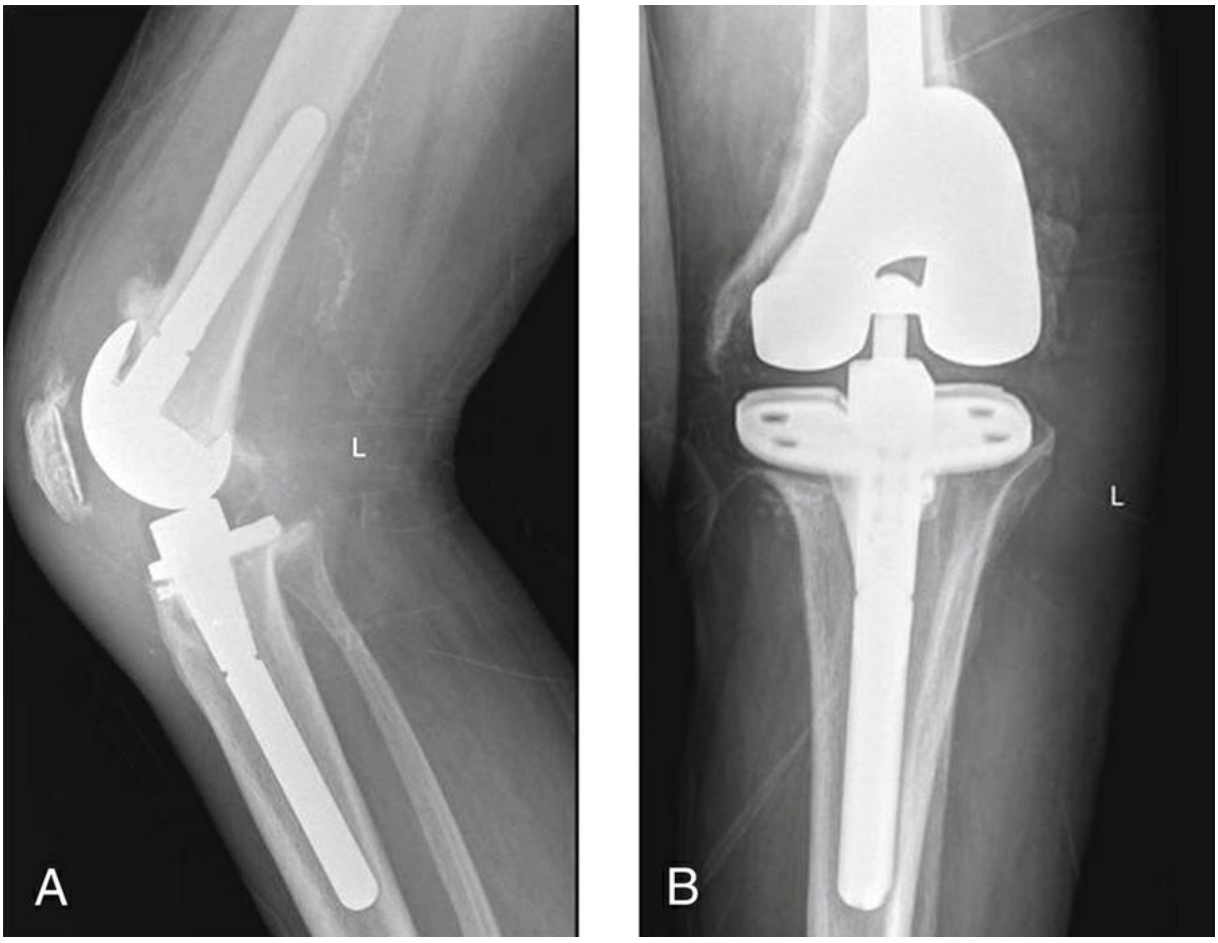

FIGURE 1 Lateral (**A**) and AP (**B**) radiographs of the knee in a patient with periprosthetic joint infection demonstrating cortical resorption, focal osteolysis, and periosteal reaction.

V. General Treatment Principles

A. Overview
   1. Treatment of PJI usually involves multiple procedures.
   2. The treatment also usually involves a prolonged course of antimicrobial therapy.

B. Characteristics of PJIs
   1. Biofilm formation

a. Biofilm formation is characteristic of PJI because of certain organisms (eg, *Staph* spp, *Pseudomonas*); the biofilm is believed to form and establish within 4 weeks.
b. Bacteria produce an extracellular matrix, such as a glycocalyx, that facilitates adherence to the implant surface and acts as a defense against antibiotics and the host's immune system (Figure 2).
c. Both the diagnosis and eradication of a PJI are difficult after a biofilm has formed.
d. The sessile bacteria within a biofilm are phenotypically and metabolically distinct from their planktonic counterparts because of differential gene expression.
e. For established infections, the removal of the prosthesis is recommended.
f. Early postoperative and acute hematogenous infections are less likely to be associated with the development of a biofilm or prosthetic loosening; the chance of eradicating infection without prosthetic removal is greater in these cases than in cases of indolent disease.

2. Microbial colonization
a. Microbial colonization can occur at the time of prosthetic implantation.
b. It can also result from the direct spread of a pathogen from a contiguous focus or from hematogenous seeding.

C. Treatment options
1. Surgical
a. Débridement with retention of a prosthesis
b. Two-stage exchange arthroplasty—Resection arthroplasty with planned reimplantation of a new prosthesis
c. One-stage exchange arthroplasty has also been gaining popularity in the United States as a potential treatment for both acute and chronic PJI, in select group of patients
d. Definitive resection arthroplasty
e. Arthrodesis (knee only)

f. Amputation

2. Nonsurgical—Suppressive antimicrobial therapy

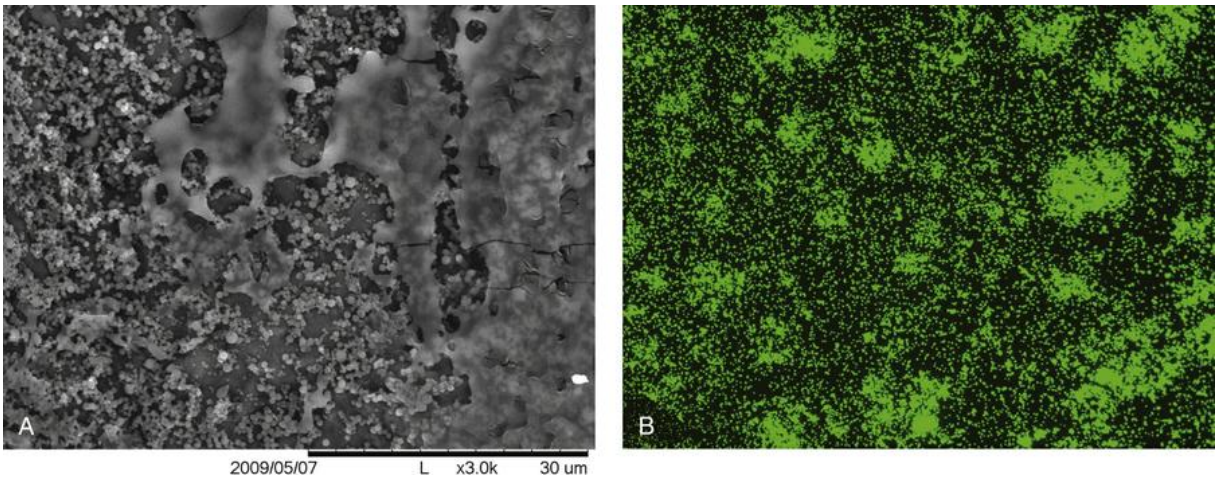

FIGURE 2 Images of Staphylococcus aureus biofilm. **A**, Scanning electron micrograph shows S aureus organisms that were allowed to grow on cortical bone struts for 12 hr and demonstrates reticulate biofilm formation, which is seen covering and protecting the bacteria (on the right side of the photograph). **B**, A fluorescence micrograph shows S aureus organisms that were allowed to colonize the surfaces of titanium alloy foils for 6 hr and washed and stained with fluorescent dye. The attached bacteria are seen organizing in colonies that have begun to organize into a biofilm, giving the appearance of large, solid patches rather than individual bacteria.

VI. Surgical Treatment

A. Two-stage exchange/replacement arthroplasty is the preferred treatment of a PJI that has persisted for many weeks.
   1. Procedure
      a. Removal of prosthesis
      b. Surgical débridement of the joint
      c. Placement of antibiotic spacer
      d. Administration of antimicrobial agents with subsequent delayed reimplantation of the prosthesis
   2. Prerequisites
      a. Adequate patient bone stock

b. Medical fitness of the patient for multiple surgical procedures
c. Reimplantation relies on confirmation of infection control (declining serologic parameters, wound healing, and negative results of microbiologic tests of joint aspirate if performed)

3. Antimicrobial agents are administered for 4 to 6 weeks following resection arthroplasty and placement of antibiotic spacer.
4. Before reimplantation, antimicrobial therapy should be stopped for at least 2 weeks before joint fluid aspiration and repeat serologies.
5. The interval between the removal of a prosthesis and its reimplantation varies highly.
   a. No specific protocol exists for this two-step process, but in the case of PJI of a total knee arthroplasty, reimplantation within 2 weeks is successful in approximately 35% of instances, compared with success rates of 70% to 90% with delayed reimplantation (>6 weeks) and more extensive antimicrobial therapy.
   b. The proper timing of reimplantation after parenteral antibiotic therapy should be based on the clinical appearance of the wound and improvement in serologic markers of infection such as the CRP concentration and the ESR.
      At the time of reimplantation, tissue specimens should be sent for culture +/− histopathologic evaluation.
      Reimplantation is indicated when all preoperative and intraoperative indices are acceptable.
      If a frozen tissue section indicates continued "acute inflammation," débridement of the wound should be repeated, and a new cement spacer placed.
6. Antibiotic-impregnated spacers (static or dynamic) are often used in the interim between prosthetic removal and reimplantation (Figure 3).
   a. Dynamic spacers allow joint motion and provide greater patient satisfaction and ease of revision.
   b. Static spacers allow the delivery of higher doses of antibiotics; in addition, the lack of motion may provide a more favorable

environment for wound healing in the setting of a compromised soft-tissue envelope.

c. Both dynamic and static spacers can become displaced and/or dislocated.

d. There is no difference in infection eradication rates between static versus dynamic spacers. There are data that suggest improved final range of motion in knees treated with a dynamic spacer.

7. Antibiotic-impregnated cement should be used in a cemented reimplantation. Noncemented reimplantation in the hip has a better outcome than cemented reimplantation.

B. One-stage exchange/replacement arthroplasty

1. Procedure

a. All prosthetic components, infected bone, and soft tissue are excised.

b. The new prosthesis is implanted during the same surgery in which the old prosthesis is removed.

c. Antibiotics are routinely administered for a variable period following the revision.

2. Indications

a. Used more commonly in Europe than in the United States.

b. Local delivery of antibiotics is often recommended and achieved with antibiotic-impregnated cement (if used).

c. The pathogen must be identified preoperatively to facilitate the appropriate choice of an antibiotic-laden bone cement.

3. Advantages

a. Single procedure

b. Lower cost

c. Earlier mobility

d. Patient convenience

4. Disadvantage—Risk of recurrent infection from residual microorganisms

5. Outcomes

a. Overall success rates for both one-stage hip and knee

reimplantation have varied (75% to 100%) and have not been as high as for two-stage reimplantation.

b. Successful outcomes are more likely in the following circumstances

Infection caused by a low-virulence organism with a good antibiotic-sensitivity profile

Patient not immunocompromised

No sinus tract formation

Healthy soft tissue

Full débridement

Prolonged course of postoperative antibiotic therapy

No bone graft used

C. Débridement with retention of prosthesis

1. Procedure
   a. Débridement of infected tissue and exchange of modular components (eg, femoral head, polyethylene insert) of a prosthesis with high-volume irrigation
   b. Prolonged postoperative antibiotic therapy
2. Indications—Débridement with retention of a prosthesis can be considered when PJI develops acutely, either in the early postoperative period or as a result of hematogenous seeding (eg, after a clear inciting event such as dental extraction in a previously asymptomatic, healthy host).
3. Advantages—Limited surgery with preservation of prosthesis and bone stock
4. Disadvantages
   a. Risk of an infected/colonized foreign body left in place
   b. Mean failure rate of 68%, depending on the outcome factors listed above.
   c. An initial débridement and irrigation may potentially compromise the ultimate success of a two-stage exchange arthroplasty.

D. Resection arthroplasty

1. Procedure

a. Definitive removal of all infected components and tissue
b. No plan for subsequent implantation

2. Indications—Currently limited, but include the following:
    a. Poor quality of bone and soft tissue
    b. Recurrent infections
    c. Infection with multidrug-resistant organism
    d. Medical conditions that preclude a major procedure (such as reimplantation)
    e. Failure of multiple previous exchange arthroplasties.
    f. Acceptable as an alternative in elderly, nonambulatory patients
3. Disadvantages
    a. Shortened limbs
    b. Poor function
    c. Patient dissatisfaction
4. Outcomes—Overall success rate of resection arthroplasty in eradicating infection depends on whether the hip or the knee is involved.
    a. For total hip arthroplasty, the success rate is between 60% and 100%.
    b. For total knee arthroplasty, the success rate is 50% to 89%.

E. Arthrodesis
1. Procedure—Results in bony ankylosis of a joint
2. Indications—When subsequent joint reimplantation is not feasible because of recurrent infection with virulent organisms
3. Outcomes—Overall success with both eradication of infection and bony fusion can be achieved in 71% to 95% of cases.

F. Amputation
1. Procedure—Transfemoral amputation
2. Indications
    a. Recalcitrant infection of a total knee arthroplasty after failure of all other options
    b. Intractable infection with severe pain, soft-tissue or vascular compromise, and bone loss so severe as to preclude the use of a prosthesis

G. Antimicrobial therapy
    1. May be curative when an infected prosthesis/joint is removed and periprosthetic tissue is adequately débrided
    2. Antibiotics should be withheld until aspiration or intraoperative cultures are obtained, unless overwhelming sepsis is present to prevent false-negative results.
    3. Initial empiric therapy for most common pathogens is a first-generation cephalosporin. Vancomycin is preferred when any of the following factors are present:
        a. True sensitivity to penicillins
        b. History of methicillin-resistant *Staphylococcus aureus* (MRSA) infection
        c. Exposure to MRSA (in institutionalized patients)
        d. Infection by an unidentified organism
    4. Following identification of the pathogen and susceptibility test results, the antibiotic regimen should be tailored to the findings.
    5. Antimicrobial-impregnated cement beads/spacers should be used to provide high local concentrations of antibiotics in the periarticular space as part of the two-stage exchange.
    6. Antimicrobial agents should be given systemically for a minimum of 4 to 6 weeks between the first and second stage of a two-stage exchange arthroplasty.

FIGURE 3 Antibiotic-containing cement spacers used in two-stage exchange arthroplasty. **A**, AP radiograph of a dynamic hip spacer. **B**, AP radiograph of a static hip spacer (note Luque wires used to fix the trochanteric osteotomy). **C**, Lateral radiograph of a dynamic knee spacer. **D**, AP radiograph of a displaced static knee spacer. **E**, AP radiograph of a static knee spacer using an intramedullary nail to prevent displacement.

VII. Nonsurgical Treatment

A. Treatment—Suppressive antimicrobial therapy

B. Indications—Considered for frail, elderly, and medically infirm patients in whom surgery is not possible or is refused by the patient.
C. Goals
    1. Relief of symptoms
    2. Maintenance of joint function
    3. Prevention of systemic spread of infection rather than its eradication
D. Outcomes
    1. Successful in only 10% to 25% of cases
    2. Complications occur in 8% to 22% of patients.

VIII. Antimicrobial-Impregnated Devices

A. Antimicrobial-impregnated devices consist of solid spacers, beads, or dynamic spacers.
B. Doses of antibiotics in spacers
    1. For each bag of prosthetic cement (40 g), at least 3.6 g of an aminoglycoside (such as tobramycin) and 3 g of vancomycin are preferred for synergistic elution kinetics. A maximum of 8 g total weight of antibiotic combination may be added before the working property (such as moldability) of the cement is affected.
    2. Gentamicin is also available in powder form in some institutions and may be used in place of tobramycin.
    3. The dose of antibiotic added to the cement should be based on the patient's renal function as well as the type of cement used. Palacos (Zimmer, Warsaw, IN) cement provides better elution of antibiotics than any other commercially available polymethyl methacrylate cement.
    4. For fungal infections, 300 to 600 mg of voriconazole should be used in addition to 1 g of vancomycin and 2.4 g of tobramycin.
C. Advantages of spacers
    1. Reduce dead space
    2. Provide joint stability

3. Deliver high local doses of antimicrobial agents

D. Disadvantages of spacers
   1. Potential for allergic reactions or local or systemic toxicity
   2. Potential for emergence of antibiotic-resistant organisms
   3. Heat-labile antimicrobial agents cannot be added to prosthetic cement. (Tobramycin, vancomycin, gentamicin powder, and amphotericin-B are heat-stable antimicrobial agents.)
   4. High doses of antimicrobial agents may adversely affect the mechanical properties of the bone cement. This is an issue in the definitive fixation during reimplantation, but not in the temporary use of an antibiotic-releasing spacer.

Top Testing Facts

1. Factors predisposing to PJI are postoperative surgical site infection, hematoma formation, complications of wound healing, malignant disease, prior joint arthroplasty, prior surgery on or infection of the joint or adjacent bone, perioperative nonarticular infection, an international normalized ratio greater than 1.5, rheumatoid arthritis, psoriasis, and diabetes.
2. Pain at the implant site is a consistent symptom of infection in more than 90% of cases of PJI.
3. A periosteal reaction, scattered foci of osteolysis, and generalized bone resorption in the absence of implant wear are radiographic signs of periprosthetic infection. When infection is clinically suspected but cannot be confirmed by aspiration or serology, bone scanning may be performed.
4. ESR and CRP are nonspecific markers of inflammation that are very useful in diagnosis when combined. The CRP concentration normalizes within 21 days of surgery, whereas ESR may take up to 90 days to normalize. A continuously high CRP concentration and ESR should raise concern for infection.
5. Joint aspiration is performed when infection is strongly suspected. Aspiration has sensitivity of 57% to 93% and specificity of 88% to 100%. The sensitivity can be improved by serial aspiration.
6. Molecular techniques are currently being evaluated, and biomarkers for the diagnosis of PJI are continually being identified and developed.
7. Two-stage exchange arthroplasty (ie. Resection arthroplasty + antibiotic

spacer followed by reimplantation) is the preferred method of treatment for chronic PJI.

8. Incision and débridement is potentially effective for infections occurring within 4 to 6 weeks of index arthroplasty or after an inciting event such as dental extraction in a healthy host.
9. In the workup of a patient with possible PJI, antibiotics should be stopped for a minimum of 2 weeks before obtaining intra-articular culture. However, a single dose of prophylactic antibiotics does not alter intraoperative culture results in PJI. Therefore, preoperative prophylactic antibiotics should not be withheld to avoid affecting cultures before revision surgery in which a positive preoperative culture aspiration has already been obtained.
10. Spacers reduce dead space, provide joint stability, and deliver high local doses of antimicrobial agents.

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