

Bearing surfaces and wear

Overview

- In total joint replacement, both articulating parts of the joint are replaced by prosthetic implants [52].
- Joint replacement bearings may be hard-on-soft, such as metal-on-polyethylene [52].
- Joint replacement bearings may be hard-on-hard, such as ceramic-on-ceramic [52].
- All joint replacements have articulations, which are parts that move against each other [52].
- All articulations produce wear [52].
- Usually the harder material causes wear of the softer material [52].
- Wear can be accelerated by roughening of the surfaces, such as by scratching [52].
- Wear can be accelerated by interposition of third bodies, such as cement fragments becoming trapped in the joint [52].
- Metal-on-metal bearings became popular in hip replacement with over one million such devices implanted worldwide [52].
- Metal-on-metal bearings have been associated with higher incidences of failure due to production of cobalt and chrome debris [52].
- The use of metal-on-metal bearings has been almost entirely abandoned [52].
- Joint replacement components are fixed to the host bone with acrylic cement or by a cementless press-fit technique [52].

Anatomy & Pathophysiology

BONY ANATOMY

- The hip is a multiaxial joint formed by the articulation between the pelvis and femur, connecting the axial skeleton and the lower extremity [16].
- The hemipelvis comprises three bones: the ilium, ischium, and pubis, which unite at the triradiate cartilage within the concave acetabulum [16].

- The acetabulum comprises an articular crescent-moon-shaped lunate surface and a nonarticular central fossa that serves as the attachment point for the ligamentum teres [16].
- The acetabulum is incomplete inferiorly, forming a notch through which vital blood vessels and nerves pass to supply the joint [16].
- The femoral head forms two-thirds of a sphere, with a small depression at its center from which the ligamentum teres extends [16].
- The neck-shaft angle of the femur averages 125° [16].
- Normal version, defined as the head-neck angle in the frontal plane, averages 15 to 20° [16].
- The acetabulum is normally anteverted 15 degrees and obliquely oriented in the coronal plane 45 degrees caudally [22].
- The posterosuperior articular surface of the acetabulum is thickened to accommodate weight bearing [22].
- The inferior surface of the acetabulum contains the acetabular (cotyloid) notch, which is bound by the transverse acetabular ligament [22].
- The femoral neck is normally anteverted approximately 14 degrees in relation to femoral condyles, with a range of 1 to 40 degrees [22].
- The femoral neck-shaft angle averages 127 degrees, beginning at 141 degrees in the fetus [22].
- The mean femoral neck-shaft angle in the adult is 130° ± 7° [27].
- The mean anteversion of the femoral neck is 10° ± 7° [27].
- The weakest area in the femoral neck is located in the Ward triangle [27].
- The calcar femorale is a medial area of dense trabecular bone that transfers stress from the femoral shaft to the inferior portion of the femoral neck [27].

SOFT TISSUE ANATOMY

- The acetabular labrum is a fibrocartilaginous ring attached to the rim of the acetabulum that extends the articulating surface area and increases femoral head coverage [16].
- The labrum is triangular in cross section, which contributes to its ability to create a pressurized seal of the central compartment of the hip during loading [16].
- Only the external one-third of the labrum contains blood vessels, leaving the majority of the structure avascular and limiting its healing ability following injury [16].
- The labrum is highly innervated, with the presence of both mechanoreceptors and nociceptors [16].
- The labrum is absent in the area of the inferior acetabular notch, where the transverse acetabular ligament serves as the continuation of the labrum [16].
- The hip is surrounded by a dense fibrous capsule extending from the periphery of the acetabulum to the intertrochanteric line of the femoral neck [16].
- The iliofemoral ligament is Y-shaped and is the thickest and strongest of the three main ligaments supporting the hip [16].

- The iliofemoral ligament functions to limit external rotation, while its lateral arm limits extension of the joint [16].
- The ischiofemoral ligament extends from the ischial margin of the acetabulum to the greater trochanter of the femur and restricts internal rotation motion [16].
- The pubofemoral ligament extends from the obturator crest of the pubic bone to the femoral neck and acts to limit abduction of the joint [16].
- Deep fibers from the iliofemoral, ischiofemoral, and pubofemoral ligaments merge to form the zona orbicularis [16].
- The hip capsule attaches anteriorly and posteriorly along the periphery of the acetabulum outside the labrum [17].
- The hip capsule attaches to the femur anteriorly along the intertrochanteric crest, while on the posterior side it attaches only partially, leaving the basicervical region and intertrochanteric region extracapsular [17].
- The iliofemoral ligament becomes taut in full extension, preventing anterior dislocation and hyperextension of the hip [17].
- The ischiofemoral ligament reinforces the posterior capsule and provides a check to internal rotation of the hip [17].
- The twisted orientation of the hip ligaments provides a screw mechanism for the hip in full extension [17].
- The ligamentum teres originates in the cotyloid fossa and attaches on the fovea of the femoral head [17].

VASCULAR ANATOMY

- In adulthood, the major blood supply to the femoral head is from the medial femoral circumflex and lateral epiphyseal arteries [30].
- From birth to approximately 4 years of age, the major blood supply to the femoral head comes from the medial and lateral femoral circumflex arteries, with major contributions from the artery of the ligamentum teres [30].
- From the age of 4 years to adulthood, the posterosuperior and posteroinferior retinacular arteries from the medial circumflex artery are the major blood supply to the femoral head [30].
- The medial femoral circumflex artery is the main blood supply to the femoral head and terminates in the posterior aspect of the extracapsular arterial ring [27].
- The lateral group of ascending branches from the extracapsular arterial ring is the main blood supply to the femoral head [27].
- The artery of the ligamentum teres arises from either the obturator or medial femoral circumflex artery and does not provide sufficient blood supply to maintain the viability of the femoral head [27].
- Fractures that disrupt the ascending blood flow to the lateral epiphyseal vessel have an increased risk of osteonecrosis [27].

BIOMECHANICS AND KINEMATICS

- The hip joint is inherently stable because of its relatively rigid ball-and-socket configuration and high conformity [51].
- In the sagittal plane, hip flexion-extension motion can exceed 145° with the knee in flexion [51].
- In the frontal plane, the hip abduction arc can be 120°, reaching 180° with training [51].
- In the transverse plane, the arcs of internal and external rotation are approximately 30° and 60°, respectively [51].
- The peak contact force in the hip joint during walking is approximately 2.5 times body weight [51].
- The push-off phase in running generates a joint contact force of approximately 5.2 times body weight [51].
- The highest calculated forces and torques across the hip joint occur when descending stairs [51].
- An increase in femoral offset correlates with a decreased requirement of abductor force to produce a constant net hip moment, thereby decreasing joint reaction forces [51].
- A decrease in the abductor muscle force disrupts joint stability, triggering a reactive neuromuscular mechanism that increases muscular cocontraction and joint reaction forces [51].
- Increasing the joint reaction force at the hip may increase the wear rate of the implant [51].

WEAR MECHANISMS

- Wear is defined as the removal of surface material by mechanical motion caused by friction, motion, and loading of an interface between materials [12].
- Abrasive wear occurs when a rougher, harder surface moves against a softer surface, generating particulate debris from the softer surface [12].
- Adhesive wear results between two moving objects in contact whereby a thin layer of material is transferred from one surface to another [12].
- Third-body wear results when an additional particle is present between the two main bearing surfaces, leading to friction and loss of material at the contact surface [12].
- Adhesive wear predominates in the metal-on-polyethylene bearings used in total hip arthroplasty [3].
- Delamination, abrasion, and adhesive wear are commonly seen with total knee arthroplasty [3].
- There are four modes of wear: between primary bearing surfaces, between one bearing surface and a nonbearing surface, third-body wear, and between two nonbearing surfaces [3].
- Hip and knee joint simulators are the accepted means for obtaining preclinical test data on wear performance and produce wear particles of similar size and shape to those observed in vivo [3].
- Wear is measured gravimetrically on the basis of the small amount of weight a material loses during its use, with 1 million cycles of test use equal to 1 year of clinical use [3].
- Recent literature has shown that some patients experience nearly 2 million cycles of activity per year [3].
- Friction between two sliding surfaces depends on the applied load and is independent of the area of contact or speed of movement [26].

- Normal human joints possess coefficients of friction that are about ten times lower than those of various combinations of prosthesis-bearing materials [26].
- Metal on ultra-high molecular weight polyethylene produces a better coefficient of friction than other combinations, which is improved further if the metal is replaced by a ceramic such as alumina or zirconium [26].
- Synovial fluid reduces the coefficient of friction by forming a fluid film lubrication layer or a molecular-width boundary lubrication coating [26].
- Wear is proportional to the load and distance of movement between two surfaces [26].
- Metal wear particles may cause local inflammation, scarring, and occasionally a toxic or allergic reaction [26].
- Metal wear particles may cause implant loosening following their uptake by macrophages and subsequent activation of osteoclastic bone resorption [26].
- Metal wear particles may provoke a lymphocyte-dominated vasculitis-associated reaction locally [26].
- The presence of metal wear particles has been demonstrated in lymph nodes and other organs far distant from the implant [26].

CORROSION MECHANISMS

- Corrosion is defined as an electrochemical process in metallic materials that cleaves metallic bonds resulting in the loss of positively charged metal ions to the environment [43].
- Pitting corrosion is the most severe form of corrosion of metals, resulting in damage to a metal-containing orthopaedic device and the often toxic release of metal ions [43].
- Pitting corrosion begins in defects of the thin protective oxide layer on a metallic prosthetic component or metal-containing implant [43].
- Surgical stainless steel (A316L) and other alloys of iron are subject to pitting corrosion, while titanium and its alloys, as well as cobalt/chromium/molybdenum/carbon (CoCrMoC) alloys, do not generally exhibit pitting corrosion [43].
- Crevice corrosion is a localized attack that can occur when a crevice geometry is created [43].
- Crevice corrosion often occurs in the threads of screws, weldments, bolted parts, or interference fits such as a hip neck pressed into a femoral stem [43].
- A crevice geometry can potentially create ionic gradients such that the pH can reach as low as 1 [43].
- Corrosion fatigue and stress corrosion cracking are forms of corrosion caused by the combined effects of the chemical environment and mechanical forces on a metal or alloy [43].
- Stress corrosion cracking is a common corrosion mechanism in titanium, its alloys, and CoCrMoC [43].
- Galvanic corrosion results from a difference in the electrochemical potential of two metals or metal alloys that are in electrical contact with one another in an electrically conductive medium [43].
- Fretting corrosion occurs at contact sites between materials that are subject to micromotion in relation to one another when a load is imposed on them [43].
- Titanium and its alloys are highly susceptible to fretting corrosion [43].

- Degradation of nonmetallic orthopaedic biomaterials such as polymers can occur through depolymerization, loss of cross-linking, oxidative degradation, leaching of additives, hydrolysis, and crazing or stress cracking [43].

BEARING SURFACE PATHOPHYSIOLOGY

- Conventional polyethylenes originally sterilized with gamma irradiation in air underwent oxidative degradation, resulting in suboptimal wear characteristics when implanted in vivo [2].
- Highly cross-linked polyethylenes that are heated at or above the melting temperature and/or annealed have shown improved wear characteristics in vitro and in vivo up to 10 to 15 years postoperatively [2].
- The particle burden from highly cross-linked polyethylene is less, although the particles are slightly smaller in size [2].
- Ceramic-on-ceramic bearings generate few wear particles secondary to extremely low volumetric wear, but their biologic potential is similar to polyethylene [2].
- Most ceramic wear particles are in the nanometer size range, although damaged surfaces can generate particles of a larger size [2].
- Issues related to ceramic particle generation include surface damage during initial placement, loss of the lubricating layer, striped wear, suboptimal placement with impingement or edge loading, chipping, and catastrophic fracture [2].
- Metal-on-metal bearing surfaces have been used for over four decades [2].
- Wear with metal-on-metal bearings is particularly low because of the smaller clearance of the components that generates thin fluid film lubrication and the self-polishing nature of this articulation [2].
- Implants manufactured with higher carbon alloys have demonstrated better wear characteristics compared with those with lower carbon alloys [2].
- In metal-on-metal arthroplasty, metallic debris is produced in greater quantity than in metal-on-polyethylene, with particles in the order of 10 to 50 nm and a large surface area [2].
- Ions of cobalt and chromium are produced by metal-on-metal bearings and can be found in surrounding and remote tissues, blood, and urine [2].
- Although high levels of cobalt and chromium ions are associated with specific types of cancer in animal models, there is no evidence of this in humans to date [2].
- Retrieval specimens from metal-on-metal prostheses demonstrate diffuse and perivascular infiltrates of T and B lymphocytes and plasma cells, high endothelial venules, massive fibrin exudation, accumulation of macrophages with drop-like inclusions, and infiltrates of eosinophilic granulocytes and necrosis [2].
- Metal-on-metal retrievals show pronounced ulceration superficial to areas demonstrating peri-lymphocytic vascular infiltration [2].
- Lymphocytic infiltration is more pronounced in specimens from metal-on-metal cases with prosthesis loosening compared with autopsy specimens or those undergoing arthrotomy [2].
- Degradation products from metal-on-metal implants may be associated with an allergic hypersensitivity reaction, confirmed by a positive lymphocyte transformation test in 10/16 patients (62%) [2].

- Debris produced by metal-on-polyethylene bearings is primarily polymeric and evokes a nonspecific, nonantigenic chronic inflammatory and foreign body reaction [2].
- Metal-on-metal articulations produce metallic byproducts that are soluble and can complex with serum proteins to form haptens, subsequently causing a hypersensitivity reaction mediated by the adaptive immune system involving T and B lymphocytes [2].
- The most common metallic sensitizers include nickel, cobalt, and chromium [2].
- Rarely, metals such as titanium, vanadium, and tantalum function as sensitizers [2].
- This allergic reaction is classified as a type IV delayed hypersensitivity immune reaction [2].
- Corrosion byproducts including CrPO₄ may develop from metal-on-metal bearing surfaces and other nonarticulating locations such as the femoral head and trunnion [2].
- Alumina ceramic has a surface finish smoother than metal implants due to its high density [10].
- Ceramic is harder than metal and more resistant to scratching from third-body wear particles [10].
- The liner wear rate of alumina-on-alumina has been shown to be 4000 times less than cobalt-chrome alloy-on-polyethylene [10].
- Ceramic wear was measured at less than 0.025 mm/year in a series of patients with a minimum of 18.5 years' follow-up [10].
- Ceramic head fracture is more common with smaller head sizes and shorter neck lengths [10].
- Application of a ceramic femoral head onto a stem trunnion with wear or surface damage can produce uneven load distribution within the head and contribute to fracture [10].
- Impingement between the femoral neck and rim of the ceramic acetabular component can produce chipping or complete fracture of the acetabular insert [10].
- Repetitive contact at extremes of motion can lead to notching of the metal femoral neck by the harder ceramic and initiate failure [10].
- Ceramic wear has been greater when the acetabular component has been implanted in an excessively vertical orientation [10].
- "Stripe wear" on retrieved ceramic heads describes a long, narrow area of damage resulting from contact between the head and the edge of the ceramic liner [10].
- Stripe wear occurs with edge loading when the hip is flexed, as with rising from a chair or stair climbing [10].
- The incidence of squeaking in ceramic-on-ceramic implants is generally low but has exceeded 10% in some series [10].
- The onset of squeaking usually occurs more than 1 year after implantation, and the development of stripe wear has been implicated in noise generation [10].
- Osteolysis has been reported around first-generation alumina ceramic implants in instances of high wear [10].
- Wear particles from ceramic are typically produced in smaller numbers and are of smaller size than seen with polyethylene [10].

- The cellular response to ceramic particles seems to be less than that to polyethylene [10].
 - **Alumina ceramic is inert, and ion formation does not occur [10].**
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Investigations

RADIOGRAPHY

- Conventional radiographs remain critical in the initial imaging evaluation of the hip [5].
- A complete hip series usually consists of an anterior-posterior (AP) pelvis, a centered AP hip, a lateral view (frog-leg, cross-table, Dunn 45° or 90°), and a false-profile (Lequesne) view [5].
- Osteoarthritis of the hip can be categorized using the Kellgren-Lawrence classification, which is a 4-point grading system classified into doubtful, mild, moderate, and severe [5].
- Osteoarthritis of the hip can be categorized using the Tönnis classification, which is a 3-point grading system categorized into mild, moderate, and severe [5].
- Radiographic and clinical severity of osteoarthritis do not necessarily correlate, particularly if radiographs are non-weight-bearing or if false-profile views are not included [5].
- Acetabular morphology is assessed on AP pelvis radiographs to evaluate acetabular overcoverage and undercoverage [5].
- The femoral head-neck junction morphology is often assessed using the alpha angle [5].
- Some studies have shown that radiographs, in particular the Dunn 45° view, may be more accurate for determining the alpha angle measurement than CT or MRI [5].
- Coxa profunda is diagnosed when the fossa line touches or is medial to the ilioischial line on an AP pelvis radiograph [5].
- The femoral head extrusion index is defined by the length of the femoral head that lies beyond the acetabulum as a percentage of the total horizontal width of the femoral head [5].
- Femoral head extrusion index values greater than 25% are considered abnormal [5].
- The Tönnis angle is defined by the angle of the acetabular sourcil and a line parallel to the transverse pelvis axis [5].
- Tönnis angles between 0° and 10° are considered normal [5].
- The lateral center-edge angle, or center-edge angle of Wiberg, is the angle between a line from the center of the femoral head perpendicular to the transverse pelvis axis and a second line from the center of the femoral head to the superolateral most point of the acetabulum [5].
- Center-edge angles of 20°–40° are considered normal, while angles from 20° to 25° are considered borderline [5].

- The “crossover” sign on an AP pelvis radiograph indicates acetabular retroversion related to lateralization of the anterior acetabular wall relative to the posterior acetabular wall [5].
- Pelvic tilt or rotation may lead to false-positive and false-negative “crossover” signs on AP pelvis radiographs [5].
- For neutral pelvic tilt, the sacrococcygeal joint should be between 3 and 5 cm above the superior border of the symphysis pubis [5].
- Radiographs can be used to diagnose fractures, developmental dysplasia of the hip (DDH), femoroacetabular impingement (FAI), and osteoarthritis [5].
- Radiographs remain integral to the assessment of fractures and can be supplemented with CT to further investigate suspected occult fractures, define fracture morphology, and assist in preoperative planning [5].
- Radiographs can serially assess hardware positioning and evaluate symptomatic hardware related to open reduction and internal fixation and total hip arthroplasty [5].
- The AP pelvis view is used to assess acetabular anatomy, including version, acetabular coverage, and femoral head sphericity [6].
- Various lateral views, most commonly the 45° Dunn view and frog-leg lateral, can be used to assess femoral head sphericity and head-neck offset [6].
- Plain radiographs are the first imaging studies obtained for patients presenting with hip pain and can determine the presence of fractures, degenerative changes, and abnormal joint morphology [34].
- Standard AP radiographs of the hip and pelvis are obtained to examine bony architecture, check for evidence of joint space narrowing or changes to bone quality, and quantify femoral head coverage [34].
- The Dunn view and frog leg view are appropriate to measure the alpha angle to determine the presence of impingement [34].
- Plain radiographs include AP and lateral views of the hip, with AP pelvis and Judet views used after reduction to evaluate associated acetabular fractures in hip dislocations [31].
- Plain radiographs include AP and lateral views of the hip for the diagnosis of femoral head fractures [31].

MAGNETIC RESONANCE IMAGING

- MRI is the modality of choice for patients suspected of soft tissue or intra-articular pathology, given its superior sensitivity and specificity [34].
- Conventional MRI is effective at identifying osteochondral injuries, musculotendinous pathologies, and inflammation [34].
- Magnetic resonance arthrography (MRA) is more appropriate to determine injuries to the labrochondral structures and the ligamentum teres and identify the presence of loose bodies and synovial chondromatosis [34].
- The utility of MRA in the accurate detection and staging of articular cartilage lesions is reduced, with sensitivity reported to be less than 50% compared with arthroscopic findings [34].
- Recent advances in MRI imaging techniques, such as delayed gadolinium-enhanced MR imaging and T2* mapping, allow for a more in-depth analysis of the structure of articular cartilage [34].

- Delayed gadolinium-enhanced MR imaging and T2* mapping were effective at detecting early changes to the articular cartilage surfaces of patients with hip dysplasia and femoroacetabular impingement [34].
- MRI or magnetic resonance arthrography provides information regarding the integrity of the acetabular labrum and articular cartilage [6].
- The anatomy of the proximal femur as well as the version of the acetabulum and femur may be assessed using MRI or magnetic resonance arthrography [6].
- Sensitivity to acetabular rim chondral lesions is limited with MRI or magnetic resonance arthrography [6].
- MRI can give important diagnostic information with regard to various intra-articular and extra-articular hip pathologies [44].
- Noncontrast MRI at 3T is generally adequate for diagnosing intra-articular pathology [44].
- If 3T imaging is unavailable, MRA can be considered at 1.5T for increased diagnostic accuracy [44].
- MRI is helpful in identifying femoral neck stress fracture in athletes and predicting patients that may require surgical intervention [44].
- MRI is helpful in assessing complications of conventional and resurfacing hip arthroplasties, particularly those with metal-on-metal bearing systems [44].
- Major findings that help predict histologic ALVAL scores include synovial thickening, synovitis, synovial volume, abductor disruption, and soft-tissue edema [44].
- CT is performed after reduction of hip dislocations to evaluate for associated acetabular and/or femoral head fracture and loose bodies in the joint [31].
- CT is used to evaluate the location and size of fragments and rule out associated acetabular fracture in femoral head fractures [31].
- MRI or bone scan is used to rule out occult nondisplaced stress fractures of the femoral neck [31].
- MRI is more sensitive than bone scan if the injury is less than 24 hours old [31].
- A prospective study comparing noncontrast 3T MRI to 1.5T MRA found similar accuracies between the two techniques for femoroacetabular impingement [37].
- A retrospective study evaluating the accuracy of noncontrast 3T MRI versus hip arthroscopy found accuracy for labral tears and acetabular cartilage lesions was 98% and 90%, respectively [37].

COMPUTED TOMOGRAPHY

- CT scans are effective for examining cortical and cancellous bone and can be used to create three-dimensional reconstructions of the hip for use in surgical planning [34].
- Measurements of femoral head coverage and acetabular and femoral impingement can also be performed reliably using CT images [34].
- Low-dose CT with three-dimensional reformats is particularly useful in surgical planning of complex or borderline deformities [6].
- CT overcomes the limitations of radiography by providing three-dimensional assessment of bony morphology and, to some degree, assessment of soft-tissue abnormalities [18].

- Combined with arthrography, CT can evaluate chondrolabral abnormalities, specifically in patients with contraindications to MRI [18].
- CT is helpful in fracture evaluation, particularly in the setting of negative radiographs, or for further defining fracture morphology in patients requiring surgical reduction [18].
- The multiplanar and 3D capabilities of CT make it an invaluable tool for assessing bone morphology, but at higher cost and radiation dose [44].
- 3D volume renderings are useful to aid in preoperative planning in FAI and subspine impingement [44].

ULTRASONOGRAPHY

- Ultrasonography provides real-time dynamic assessment of the hip and is useful in diagnosing soft-tissue abnormalities about the hip joint, and to a lesser degree, within the hip joint itself [18].
- Ultrasonography is particularly useful in providing real-time guidance during diagnostic and therapeutic procedures [18].
- Although ultrasonography is a valuable tool to examine pediatric hip conditions, its utility in evaluating the adult hip is limited [34].
- Ultrasonography can be an effective modality to identify musculotendinous disruptions, effusions associated with intra-articular pathology, or inflammatory conditions, such as bursitis [34].
- Ultrasonography is also being increasingly used for targeted injections into muscles, tendons, or intra-articularly around the hip, for use with corticosteroids or biologic treatments emerging as a more recognized modality [34].
- Ultrasonography allows bedside evaluation of the hip and can be used to guide interventions in the office setting [44].
- Ultrasonography uses high-frequency sound waves to produce images [45].
- A lower frequency ultrasonographic beam has a longer wavelength and less resolution but deeper penetration [45].
- A higher frequency ultrasonographic beam can provide higher resolution images of superficial structures such as tendons and ligaments [45].
- Doppler ultrasonography can be used to image blood vessels for flow velocity and direction [45].
- Elastography is an ultrasonography technique that can assess the elasticity of soft tissues and identify pathology that changes the elasticity of soft-tissue structures, like tendinopathy [45].
- Elastography is used mostly in research studies but not for clinical use at this point [45].
- Ultrasonography is noninvasive at the frequencies used for diagnostic imaging [45].
- Ultrasonography shows nonossified structures such as the femoral head and is useful to diagnose hip dysplasia and dislocation [45].
- Equipment for ultrasonography is portable and inexpensive compared with MRI and CT equipment [45].
- Highly echogenic structures, such as a foreign body that may not be visible on radiographs, can be easily detected using ultrasonography [45].

- Ultrasonography can be used to guide targeted therapy, such as injections and ablations, and is useful to guide injections and aspirations [45].
- Ultrasonography provides dynamic assessment of structures, such as tendon and nerve subluxation [45].
- Image quality and interpretation of ultrasonography depend on the experience of the ultrasonography technician and the radiologist [45].
- Ultrasonography cannot image inside bone because bone cortex reflects almost all sound waves [45].
- Internal joint structures are not well visualized with ultrasonography unless they are in a superficial location [45].

Treatment

POLYETHYLENE MODIFICATIONS AND STERILIZATION

- Conventional polyethylenes sterilized with gamma irradiation in air and stored in air-containing packaging undergo oxidative degradation, resulting in suboptimal wear characteristics when implanted [2].
- Highly cross-linked polyethylenes that are heated at or above the melting temperature and/or annealed demonstrate improved wear characteristics in vitro and in vivo up to 10 to 15 years postoperatively [2].
- The particle burden from highly cross-linked polyethylene is less, although the particles are slightly smaller in size than those from conventional polyethylene [2].
- The very small number of particles generated by highly cross-linked polyethylene compensates for the potential for increased particle-associated inflammation [2].
- Newer polyethylenes doped with the free radical scavenger vitamin D or repetitively melted and annealed may show improved wear promise [2].
- Gamma radiation sterilization in an oxygen environment causes detrimental effects that can hasten polyethylene wear [36].
- A subsurface white band representing high oxidation and chain scission appears in polyethylene sterilized by gamma radiation in an air environment over a period of years [36].
- McGovern et al. reported a failure rate of 49% at 18 months for unicompartmental knee arthroplasties sterilized by gamma radiation in an air environment and stored preoperatively for 4.4 years or more [36].
- An inverse relationship exists between the shelf life of tibial components after sterilization and the time to revision surgery in cases of gamma radiation sterilization in air [36].
- Alternative approaches to prevent accelerated oxidation include radiation sterilization and packaging in an inert gas environment, or sterilization by ethylene oxide or gas plasma [36].
- Highly crosslinked polyethylene produced by high-dose gamma irradiation with subsequent annealing has produced dramatic decreases in wear in simulated hip and knee studies [36].
- Carbon fiber-reinforced polyethylene was withdrawn from the market because of accelerated and catastrophic wear [36].

- Heat-pressing the prosthetic articular surface after milling creates a physical transition zone 1 mm beneath the articular surface, which is a region of high subsurface stress concentration [36].
- The combination of a heat-pressed transition zone and articular geometry characterized by high contact stresses led to a high rate of failure due to polyethylene delamination, particularly with thin polyethylene [36].

CERAMIC-ON-CERAMIC BEARINGS

- Alumina ceramic implants have a surface finish smoother than metal implants due to their high density [10].
- Hamadouche et al. measured ceramic wear at less than 0.025 mm/year in a series of patients with a minimum of 18.5 years' follow-up [10].
- Hot isostatic pressing and a threefold decrease in grain size have substantially improved the strength of alumina ceramics [10].
- Refinements in the tolerances of the Morse taper have reduced the incidence of ceramic head fracture [10].
- Proof testing validates the strength of each individual ceramic implant before release [10].
- A 28 mm head with short neck length has less material between the corner of the taper bore and articulating surface than a 36 mm head with longer neck length [10].
- Manufacturers have produced ceramic heads fitted with a metal sleeve for use on trunnions with wear or surface damage [10].
- Ceramic-on-ceramic arthroplasties may be more sensitive to implant malposition than other bearings [10].
- Walter et al. proposed that stripe wear occurs with edge loading when the hip is flexed, as with rising from a chair or stair climbing [10].
- The incidence of reproducible noise, particularly squeaking, in ceramic-on-ceramic implants is generally low but has exceeded 10% in some series [10].
- The onset of squeaking usually occurs more than 1 year after implantation [10].
- The development of stripe wear has been implicated in the generation of squeaking noise [10].
- A specific cementless femoral component with unique metallurgy and taper size has been implicated in several reports of squeaking [10].
- Vibrations generated at the articulating surfaces may be amplified by a more flexible stem, resulting in audible events [10].
- Wear particles from alumina ceramic are typically produced in smaller numbers and are of smaller size than those seen with polyethylene [10].
- The cellular response to ceramic particles seems to be less than that to polyethylene particles [10].
- There have been no adverse systemic effects reported with ceramic bearings [10].
- Composites of alumina and zirconia ceramic (BIOLOX delta) have reported excellent wear properties and increased fracture toughness [10].

- In a series of delta ceramic-on-ceramic total hips in patients younger than 50 years, Kim et al. found excellent survivorship, but 10% still experienced squeaking [10].
- Blakeney et al. reported a 23% incidence of squeaking when a large-diameter (32 to 48 mm head) delta ceramic-on-ceramic couple was used [10].
- The incidence of head fracture with delta ceramic is approximately 1 in 100,000 (0.001%) [10].
- The incidence of head fracture with pure alumina ceramic is 1 in 5000 (0.0201%) [10].
- Chipping of the ceramic insert on implantation has been reported in multiple series [10].
- Metal backing of the ceramic insert has been advocated by one manufacturer to prevent insertional chips and protect the rim of the ceramic from impingement [10].
- Alumina ceramic femoral heads are manufactured with only a limited range of neck lengths, and skirted heads are unavailable [10].
- Oxidized zirconium (OXINIUM) is a zirconium metal alloy placed through an oxidation process to yield an implant with a zirconia ceramic surface of approximately 5 µm in thickness [10].
- The enhanced surface of oxidized zirconium is integral to the metal substrate and not a surface coating [10].

METAL-ON-METAL BEARINGS

- Metal-on-metal bearing surfaces have been used for over four decades, first as the McKee Farrar and Ring prostheses in Great Britain [2].
- The resurgence of resurfacing arthroplasty of the hip has encouraged a reconsideration of metal-on-metal bearing surfaces [2].
- Ions of cobalt and chromium are produced by metal-on-metal implants and can be found in surrounding and remote tissues, blood, and urine [2].
- Retrieval specimens from metal-on-metal prostheses demonstrate different histological findings compared with metal-on-polyethylene implants [2].
- Macrophage-laden particles are far less pervasive in metal-on-metal specimens than in metal-on-polyethylene specimens [2].
- A subset of 19 patients with second-generation metal-on-metal articulations presented with early recurrence of preoperative pain, poor function, and joint effusion despite pristine-looking radiographs [2].
- Five of the 19 hips in the Willert et al. series subsequently developed radiolucent lines and another 7 hips developed osteolysis before revision [2].
- At surgery in the Willert et al. series, hip components were well fixed in nine patients [2].
- Characteristic histological features in metal-on-metal retrievals include diffuse and perivascular infiltrates of T and B lymphocytes and plasma cells, high endothelial venules, massive fibrin exudation, accumulation of macrophages with drop-like inclusions, and infiltrates of eosinophilic granulocytes and necrosis [2].
- Metal-on-metal retrievals showed pronounced ulceration superficial to areas demonstrating perilymphocytic vascular infiltration [2].

- Lymphocytic infiltration was more pronounced in specimens from metal-on-metal cases with prosthesis loosening compared with autopsy specimens or those undergoing arthrotomy [2].
- Degradation products from metal-on-metal implants may be associated with an allergic hypersensitivity reaction [2].
- A positive lymphocyte transformation test was found in 10/16 patients (62%) in a subsequent report confirming hypersensitivity [2].
- Metal-on-polyethylene debris is primarily polymeric and evokes a nonspecific, nonantigenic chronic inflammatory and foreign body reaction [2].
- Metal-on-metal articulations produce metallic byproducts that are soluble and can complex with serum proteins to form haptens [2].
- The hypersensitivity reaction mediated by the adaptive immune system involving T and B lymphocytes is classified as a type IV delayed hypersensitivity immune reaction [2].

TREATMENT OF POLYETHYLENE WEAR

- Indications for modular bearing change include a symptomatic patient with polyethylene wear [38].
- Symptoms prompting modular bearing change may be due to painful effusion or microfracture through an osteolytic defect [38].
- Significant linear polyethylene wear associated with progressive radiographic osteolysis with concern for impending catastrophic failure is an indication for modular bearing change [38].
- Recurrent instability and/or mechanical symptoms of subluxation are indications for modular bearing change [38].
- Implants must be well fixed to bone and adequately positioned for modular bearing change; loose implants should be revised [38].
- The most common postoperative complication of isolated head and liner exchange for polyethylene wear is dislocation [38].
- Patients generally feel well after modular bearing change and fail to allow adequate soft tissue healing, contributing to dislocation risk [38].
- Not revising poorly positioned implants increases the risk of impingement and instability [38].
- Both the liner and head must be exchanged during modular bearing change for polyethylene wear [38].
- Bone grafting of osteolytic lesions behind the cup is performed with particulate graft through cup holes or a small iliac trap door [38].
- Cementing of a polyethylene bearing into a fixed porous cup is indicated when there is a damaged or worn locking mechanism or when a replacement polyethylene bearing is not available [38].
- Optimization of the polyethylene cup position to avoid neck impingement reduces the chance of hip instability during cemented liner exchange [38].
- Deep seating of the polyethylene liner into the metal cup maximizes surface contact with cement and minimizes the risk of debonding [38].

- Roughening of the back side of the polyethylene liner insert increases surface area for bonding with cement [38].
- Roughening of the inside surface of the metal cup shell increases surface area for bonding with cement [38].
- Close matching of the polyethylene liner to the metal shell is not important when cementing the bearing [38].

GENERAL WEAR PRINCIPLES AND FAILURE MODES

- Tribology is the science and technology of friction, lubrication, and wear in interacting surfaces in relative motion [3].
- Types of wear include adhesive and abrasive wear, fatigue, and delamination [3].
- Metal-on-polyethylene has been the benchmark in bearing materials for the past four decades [3].
- Hip and knee joint simulators are the accepted means for obtaining preclinical test data on wear performance [3].
- Joint simulators have been shown to produce wear particles of similar size and shape to those observed in vivo [3].
- Wear is measured periodically and gravimetrically on the basis of the small amount of weight that a material loses during its use [3].
- One million cycles of test use is equal to 1 year of clinical use for wear measurement purposes [3].
- Fatigue, wear, and corrosion are the three major types of failures that can occur in joint replacement components [7].

References

- [2] Orthopaedic Basic Science Fifth Edition Print Ebook. Biology and Mechanics of the Skeletal Extracellular Matrix > Alternative Bearings.
- [3] Aaos Comprehensive Orthopaedic Review 3. Biomechanics and Wear in Joint Arthroplasty > I. Overview.
- [5] Orthopaedic Knowledge Update Sports Medicine 6. Imaging of the Hip > Radiography.
- [6] Aaos Comprehensive Orthopaedic Review 3. Nonarthroplasty Surgical Treatment of the Hip > I. Femoroacetabular Impingement.
- [7] Orthopaedic Knowledge Update 13 Ebook Without Multimedia. Musculoskeletal Biomechanics > Summary.
- [10] Campbell S Operative Orthopaedics 4 Volume Set. CERAMIC-ON-CERAMIC BEARINGS.
- [12] Orthopaedic Basic Science Fifth Edition Print Ebook. Biology and Mechanics of the Skeletal Extracellular Matrix > Wear and Corrosion.

- [16] Orthopaedic Knowledge Update 13 Ebook Without Multimedia. Anatomy and Biomechanics, Evaluation, Clinical Examination, and Imaging of the Hip > Osseous and Ligamentous Anatomy.
- [17] Aaos Comprehensive Orthopaedic Review 3. Surgical Anatomy of the Hip > IV. Hip Capsule and Ligaments.
- [18] Orthopaedic Knowledge Update Sports Medicine 6. Imaging of the Hip > Introduction.
- [22] Miller S Review Of Orthopaedics. SECTION 16 PATELLAR TRACKING IN TOTAL KNEE ARTHROPLASTY > LOWER EXTREMITY.
- [26] Apley And Solomon S Concise System Of Orthopaedics And Trauma. Friction and wear.
- [27] Aaos Comprehensive Orthopaedic Review 3. Fractures of the Hip > I. General Considerations.
- [30] Aaos Comprehensive Orthopaedic Review 3. Surgical Anatomy of the Hip > VI. Neurovascular Structures Surrounding the Hip.
- [31] Miller S Review Of Orthopaedics. SECTION 16 PATELLAR TRACKING IN TOTAL KNEE ARTHROPLASTY > YOUNG ADULT PROXIMAL FEMUR INJURIES.
- [34] Orthopaedic Knowledge Update 13 Ebook Without Multimedia. Anatomy and Biomechanics, Evaluation, Clinical Examination, and Imaging of the Hip > Imaging.
- [36] Campbell S Operative Orthopaedics 4 Volume Set. POLYETHYLENE AND BEARING CHOICES.
- [37] Orthopaedic Knowledge Update Sports Medicine 6. Imaging of the Hip > Annotated References.
- [38] Miller S Review Of Orthopaedics. SECTION 16 PATELLAR TRACKING IN TOTAL KNEE ARTHROPLASTY > TREATMENT OF POLYETHYLENE WEAR.
- [43] Aaos Comprehensive Orthopaedic Review 3. Biomaterials > III. Corrosion and Degradation of Biomaterials.
- [44] Orthopaedic Knowledge Update Sports Medicine 6. Imaging of the Hip > Summary.
- [45] Aaos Comprehensive Orthopaedic Review 3. Musculoskeletal Imaging* > IV. Ultrasonography.
- [51] Aaos Comprehensive Orthopaedic Review 3. Biomechanics and Wear in Joint Arthroplasty > II. The Hip Joint.
- [52] Apley And Solomon S Concise System Of Orthopaedics And Trauma. Total joint replacement.