Specialty Update

What's New in Hip Arthroplasty

By Michael H. Huo, MD, and Nathan F. Gilbert, MD

Total hip arthroplasty is one of the most clinically efficacious and cost-effective medical interventions. Surgeons and scientists have continued to produce a tremendous amount of research data related to clinical outcomes, biomaterials, surgical techniques, treatment of complications, and socioeconomic analysis. Between April 2004 and April 2005, fifty-five reports related to total hip arthroplasty were published in *The Journal of Bone and Joint Surgery (American Volume),* 140 were published in the *Journal of Arthroplasty,* and sixty-eight were published in *Clinical Orthopaedics and Related Research*. In addition, 190 abstracts on this topic were presented at the annual meeting of the American Academy of Orthopaedic Surgeons, forty-two were presented at the annual meeting of the American Association of Hip and Knee Surgeons, and eighty were presented at the fall and spring meetings of the Hip Society. There were also numerous abstracts and papers from the Orthopaedic Research Society and reports in other peer-reviewed publications. We have organized this review update into seven sections: (1) primary total hip arthroplasty (including surface arthroplasty), (2) revision, (3) bearing surface, (4) minimal incision surgery, (5) complications, (6) practice management, and (7) cost analysis. Special focus is given to two of these topics: bearing surfaces and cost analysis.

Primary Total Hip Arthroplasty

Fixation with Cement

Controversies exist with regard to the most optimal stem surface finish for cement fixation. Callaghan et al. reviewed the minimum ten-year results of 574 hip replacements that had been performed by a single surgeon using stems with three different surface finishes (5, 30, and 80 Ra). The rates of revision for aseptic loosening were 0% (5 Ra), 2% (30 Ra), and 10.8% (80 Ra). The combined rates of revision and radiographic failure were 0% (5 Ra), 3.6% (30 Ra), and 13% (80 Ra). The difference was significant between the 5-Ra and 80-Ra groups ($p < 0.05$) and between the 30-Ra and 80 Ra-groups ($p < 0.05$). The difference was not significant between the 5-Ra and 30-Ra groups. White et al. reviewed the two to five-year results of 251 hip replacements that had been performed by multiple surgeons using stems with four different surface finishes (polished, matte, rough, and precoated with methylmethacrylate). There were no differences among the four groups with regard to the clinical or radiographic outcome. Junick et al. reviewed the results of 335 consecutive hip replacements that had been performed by a single surgeon using a stem with precoated matte finish. The mean duration of follow-up was 7.4 years (range, five to eleven years). The rate of stem survival was 97.8% at ten years, with loosening as the end point. These data were in contrast to previous reports describing accelerated early debonding with this particular stem design. Surface finish may be a critical factor in the durability of fixation with cement, particularly with specific stem geometries.

Fixation without Cement

There has been little new information on the clinical outcome of cementless hip arthroplasty. Implants with a coating of hydroxyapatite have been widely used. It is appealing to apply other chemical or pharmacological additives to the implant surface for the purpose of improving fixation, preventing loosening or osteolysis, reducing infection, or delivering analgesia. Elmengaard et al. conducted a matched-pair study in which a titanium-alloy cylinder with a porous coating with or without growth factors (TGF-beta and IGF-1) was placed in the femoral condyles of nine dogs. One knee received an implant without growth factors, and the other knee received an implant with growth factors. The drill-hole was 1.5 mm larger than the diameter of the implant, thus leaving a gap between the implant and the bone. The implants were inserted to allow for full-weight loading with each gait cycle. The animals were killed at four weeks. Push-out testing demonstrated significantly greater shear strength and energy to failure in the im-

Specialty Update has been developed in collaboration with the Council of Musculoskeletal Specialty Societies (COMSS) of the American Academy of Orthopaedic Surgeons.

WHAT'S NEW IN HIP ARTHROPLASTY

plants that were coated with growth factors ($p < 0.001$). In addition, histomorphometric examination of the implant-bone interface demonstrated significantly less fibrous tissue around the implants that were coated with growth factors. That study and other similar studies provide promise that further improvement in cementless fixation can be realized in the clinical setting.

Resurfacing Arthroplasty

There has been a resurgence of interest in resurfacing arthroplasty. Sales of resurfacing implants have become one of the fastest-growing segments in the worldwide market. The use of this procedure in the United States is limited at the present time. The clinical outcome of total surface arthroplasty has been reported to parallel that of stem-type total hip arthroplasty. Amstutz et al.[1] reported on 400 metal-on-metal hybrid surface arthroplasties. The procedures were performed in a high-demand population; the mean age was forty-eight years, 73% of the patients were men, and 66% of the patients had osteoarthritis. After a mean duration of follow-up of 3.5 years, 3% of the hips required revision to a stem-type hip replacement. The survival rate was 94.4% at four years. Pain relief and functional capacity were excellent in the majority of the patients. McMinn and Daniel reported perhaps the largest single-center experience. The overall failure rate was 0.88% (nineteen of 2167) after a mean duration of follow-up of 5.8 years. The same authors also reported on the use of a minimal posterior approach for the performance of 232 consecutive surface arthroplasties. There were no significant differences in objective data such as estimated blood loss, component position, or rehabilitation when the results of these procedures were compared with the results of procedures performed with use of a conventional incision.

One of the complications of surface arthroplasty is femoral neck fracture. Mont et al. reported a high prevalence of femoral neck fractures (22%) in their first fifty cases. With more experience, the fracture rate was reduced to 0.4% (one hip) in the subsequent 250 consecutive cases. Amstutz, Campbell, and Le Duff[2] reported a fracture rate of 0.83% (five of 600). All five fractures were associated with a traumatic event. However, technical factors, including notching of the lateral cortex, out-of-axis reaming, and excessive removal of marginal osteophytes from the femoral neck, were identified as contributing risk factors. Beaule et al.[3] reviewed a subset of ninety-three surface arthroplasties that had been performed in patients younger than forty years of age. The mean duration of follow-up was 4.2 years. The authors identified thirteen hips (14%) that were considered to be failures because of revision to a stem-type hip arthroplasty, resorption of the femoral neck bone, or loosening. Radiographic analysis demonstrated a valgus position as a prerequisite for optimal durability of femoral component fixation. Silva et al.[4] analyzed hip biomechanics in a study of consecutive surface arthroplasties and compared the data with those from forty consecutive stem-type total hip arthroplasties. All procedures were performed by a single surgeon. In the surface arthroplasty group, the horizontal offset was consistently shorter in the treated hip as compared with the normal, contralateral hip. This finding was due to valgus positioning of the femoral component. In contrast, in the total hip arthroplasty group, the femoral offset was generally longer in the treated hip as compared with the contralateral, normal hip. Limb-length equalization within 1 cm was achieved with both types of reconstruction. The authors concluded that surface arthroplasty is less ideal in patients who have a substantial leg-length inequality or a varus neck-shaft angle (large offset) preoperatively.

Revision Total Hip Arthroplasty

The volume of revision surgery has continued to increase. Kurtz et al. analyzed the burden of total hip revision surgery in the United States with use of National Hospital Discharge Survey data from 1990 to 2002 and found a 60% increase. Approximately 43,000 revisions were done in 2002, accounting for 17.5% of all hip arthroplasties. Fortunately, the year-to-year revision rate did not increase over this period. Moreover, the cause of failure leading to revision surgery has changed. Lachiewicz and Soileau reviewed two series of 100 consecutive hip revisions that were performed by a single surgeon at a tertiary teaching hospital. The first 100 procedures were done in the early 1990s. The second 100 procedures were done after 2000. There were distinct differences in the indications for revision between the two groups. The contemporary group had more isolated stem revisions ($p < 0.005$), more recurrent dislocations ($p < 0.001$), and more problems with wear and osteolysis ($p = 0.03$). Bozic et al.[5] reviewed the results of 243 revisions that had been performed at a tertiary medical center. The most common mode of failure leading to revision was osteolysis, followed by loosening and recurrent dislocation.

Acetabulum

A pelvic reinforcement cage has been used most often in conjunction with structural allograft to address major acetabular bone deficiencies. Berry et al., in a study of eighty-one procedures that were performed with use of a cage from 1991 to 1998, reported that 70.3% of the cages remained in situ after a mean of 5.3 years of follow-up. The mean Harris hip score improved from 45 to 74 points. The major reasons for cage failure were loosening or instability (55%) and infection (45%). Cage fracture occurred in association with 30% of the cases of loosening. Lewallen et al., in a study from the same institution, reported on 111 hips that had been treated with a revision shell made of tantalum from 1999 to 2001. Six hips (5.4%) required a reoperation because of dislocation (four patients), wound hematoma (one patient), and the need for wire removal (one patient). No shell migrated. No cup was revised for loosening. A normal hip center was restored in 86% of the hips. Incomplete radiolucent lines at the bone-shell interface were observed in 7% of the hips. These

WHAT'S NEW IN HIP ARTHROPLASTY

surgeons also reported that they inserted a tantalum shell to bridge major bone deficiencies and supported the shell with a pelvic reinforcement cage in selected situations. The long-term durability of this device and technique remains to be validated.

Femur

Allograft-prosthesis composites have been utilized for patients with extreme femoral bone deficiencies. Hanssen et al. reported on the use of this technique in an intussusception mode. All patients had Paprosky type-III or IV femoral bone deficiencies. Major complications included one infection necessitating hip disarticulation, two recurrent dislocations, two wound hematomas, and eight intraoperative femoral fractures. The mean duration of follow-up was 5.1 years. The mean Harris hip score improved from 48 to 72 points. Of the twenty-six patients, twenty-four achieved complete union clinically and radiologically at a mean 5.5 months after surgery. This technique serves as an alternative to the use of either large-diameter extensively coated cylindrical stems or modular tapered stems for these complex reconstructions.

Another option for addressing massive femoral bone loss is to use a megaprosthesis originally designed for reconstruction following tumor resection. Parvizi and Sim[6] outlined the indications, surgical technique, and contraindications for this technique. They reviewed the clinical results in six series published from 1981 to 1995. These series included 133 hips with a mean duration of follow-up ranging from four to 11.1 years. The overall survival rate ranged from 58% to 90%. The major complications were dislocation (prevalence, 20% to 50%), fracture (prevalence, 50%), leg-length inequality (prevalence, 50%), and infection (prevalence, 16%). Berend et al.[7] reported the results for fifty-nine patients who had had a reconstruction with use of a total femoral implant for salvage of total hip arthroplasty failure. These procedures were done over a period of thirteen years. The mean age at the time of total femoral arthroplasty was seventy-four years. The mean duration of follow-up was nearly five years (range, one to thirteen years). There was significant improvement in pain and function ($p < 0.05$). The survival rate with aseptic revision as the end point was 75% at ten years. Complications included infection (prevalence, 14%) and dislocation (prevalence, 12%). One intriguing subset comprised fourteen patients who had had a previous infection. Reinfection occurred in only one of these patients. The high rate of dislocation may be reduced with use of newer constrained liners and soft-tissue reconstruction around the prostheses. The rate of infection may be reduced with use of suppressive antibiotic therapy and antibiotic-impregnated bone cement.

Bearing Surface

Wear at the bearing surface is one of the most important areas of research related to total hip arthroplasty. This is reflected by the fact that wear and osteolysis are among the most frequent causes of revision surgery. Substantial controversies remain with regard to which type of bearing surface is the most durable. Several recent reports have focused on potential problems with alternative bearing surfaces that have been introduced into wide clinical application over the past five years: highly cross-linked polyethylene, ceramic, and metal-on-metal couplings.

Highly Cross-Linked Polyethylene

The principal aim of highly cross-linked polyethylene is to reduce surface wear and oxidation. At the present time, six different types of highly cross-linked polyethylene are commercially available in the United States. They all differ in terms of the radiation dose, radiation technique, thermal treatment to remove free radicals, and terminal sterilization technique. Such differences in manufacturing can influence the wear characteristics and mechanical properties of a given material. Despite some differences, significant wear reduction in hip simulators has been shown in association with all of these new materials. Data from recent laboratory tests and clinical retrieval analysis studies have demonstrated a greater amount of free radicals in material that was made with post-irradiation annealing (heating below the melting temperature) compared with materials that were melted. Greater amounts of free radicals also were found in the material following artificial aging (5 atmospheres of oxygen at 70°C to 80°C for two weeks) and real-time aging (in an aqueous bath at 40°C) and in retrieved liners after in vivo usage.

Post-irradiation melting reduces the crystallinity of the polyethylene, whereas annealing does not. This reduced crystallinity results in a reduced modulus of elasticity and yield strength. The potential clinical relevance is related to reduction in ultimate tensile strength, in chain mobility and energy absorption, and in fatigue crack propagation. Bradford et al.[8] reported data on twenty-four liners: twenty-one highly cross-linked polyethylene liners that were retrieved after a mean of ten months of in vivo, one unused (control) highly cross-linked polyethylene liner, and two control non-cross-linked (ethylene oxide-sterilized) polyethylene liners. This particular highly cross-linked polyethylene (Durasul; Zimmer, Warsaw, Indiana) was made with a radiation dose of 9.5 Mrad at 120°C with use of electron-beam radiation, remelted at 150°C, and sterilized with use of ethylene oxide. All of the retrieved components demonstrated some evidence of wear, including scratching (prevalence, 96%), pitting (prevalence, 79%), abrasion (prevalence, 71%), surface cracks (prevalence, 67%), deformation (prevalence, 8%), and delamination (prevalence, 4%). Scanning electron microscopy demonstrated a consistent pattern of surface-crack damage parallel to and perpendicular to the machining marks. These surface cracks may have progressed to further subsurface cracking and fatigue wear with longer in vivo usage. No data on mechanical testing of these explants were provided. The findings of that study were different from previously reported in vitro testing data on the same

WHAT'S NEW IN HIP ARTHROPLASTY

material. These findings following short-term in vivo usage may not necessarily correlate with long-term wear behavior or with the in vivo behavior of other highly cross-linked polyethylenes. The authors recommended a need for modifications in hip simulator testing protocols in order to more accurately reflect the early in vivo wear characteristics that they noted.

Shen and McKellop[9] evaluated the wear characteristics of highly cross-linked polyethylene cups made with two novel methods. The principal aim of both methods was to produce cross-linking in only the superficial layer in the hope of preserving the mechanical properties of the material bulk against scratch and crack propagation. With the first method, low-energy electron beams were used to create the cross-linking, which was followed by annealing at 100°C for three to six days to reduce residual free radicals. With the second method, chemical cross-linking was produced by mixing polyethylene powder with 1% weight peroxide under compression of 6.9 MPa at 170°C. Both methods produced cross-linking to a depth of 2 to 3 mm from the surface. Simulator testing against smooth femoral heads demonstrated mean wear rates for the electron beam-irradiated materials ranging from 25.6 mm^3/million cycles (5 Mrad) to 9.2 mm^3/million cycles (15 Mrad). The mean wear rate for the chemically cross-linked material was 17.1 mm^3/million cycles, which most closely resembled that of the material irradiated with 10-Mrad (15.6 mm^3/million cycles). The wear rates for all materials increased dramatically (range, fivefold to ninefold) when testing involved articulation against roughened femoral heads. The wear rates, however, returned to earlier values when testing was changed to articulation against smooth heads again. One of the most important findings of that study was that cross-linking gradually decreased from the surface layer to the depth of 2 to 3 mm. It is hoped that this gradual transition will minimize the potential for an abrupt interface transition leading to delamination.

Harris reported on the improved mechanical properties of two new forms of highly cross-linked polyethylene. One material (cold-irradiated, mechanically annealed polyethylene) was manufactured by cold irradiation (10 Mrad) followed by compression at 130°C and annealing at 136°C. The second material was prepared by soaking irradiated polyethylene (10 Mrad) in vitamin E at 110°C. No free radicals were detected in the cold-irradiated mechanically annealed material. Free radicals were detected in the vitamin-E-soaked material. Both materials showed no oxidation following accelerated aging. The pin-on-disc wear rates for both materials were similar to those for untreated polyethylene irradiated at a dose of 10 Mrad. The fatigue strength, ultimate tensile strength, and yield strength were significantly higher for both newer materials than for the untreated polyethylene irradiated at a dose of 10 Mrad ($p < 0.01$). Essner et al. reported data on the wear and tensile properties of highly cross-linked polyethylene made with another novel method of sequential irradiation and annealing. This process involves irradiation at a dose of 3 Mrad followed by annealing at 130°C for eight hours. This is repeated three times sequentially; thus, the total irradiation dose is 9 Mrad. Sterilization was done with use of ethylene oxide. Free radical concentration was 14×10^{14} spins/g, compared with 1550×10^{14} spins/g for the conventional polyethylene (irradiated at a dose of 3 Mrad irradiation in nitrogen). Wear testing was conducted with use of two sets of liners with thicknesses of 7.5 and 4.9 mm, which articulated against 32-mm heads for 5 million cycles. Volumetric wear was 1.3 ± 0.7 mm^3/million cycles for the 7.5-mm liners and 1.5 ± 0.9 mm^3/million cycles for the 4.9-mm liners ($p = 0.085$). These wear measurements were significantly lower when compared with those associated with conventional non-cross-linked polyethylene ($p < 0.0001$) and with an earlier-generation highly cross-linked polyethylene ($p = 0.02$). Mechanical testing demonstrated no difference in yield strength or ultimate tensile strength between the sequential cross-linked and conventional polyethylenes. There was no difference between the polyethylenes with regard to crystallinity. Moreover, there was no alteration of the mechanical properties following artificial aging. These newer highly cross-linked materials have not yet been introduced into clinical use. Their efficacy in the clinical setting remains to be validated, particularly with some retrieval analysis in the future. The in vivo wear behavior may be different from the results of in vitro testing as demonstrated by Bradford et al.[8].

Clinical data have continued to validate superior wear rates in hips with highly cross-linked polyethylene. Krushell and Fingeroth reported on a case-controlled series of eighty hips, forty of which were treated with conventional polyethylene liners and forty of which were treated with highly cross-linked polyethylene liners. The femoral head size was 28 mm. Radiographic wear measurements were made at a mean of four years. There was a 59% reduction in femoral head penetration in the highly cross-linked polyethylene group (0.05 mm/year compared with 0.12 mm/year, $p < 0.001$). Wear-rate analysis is sensitive to the radiographic measurement technique. Bragdon et al. compared the Martell method with the radiostereometry technique. Measurements were made for forty-five hips at one, two, and five years after surgery. After accounting for the initial bedding-in period, the two-dimensional wear rate was lower in association with the radiostereometry method ($p < 0.05$). There was, however, no difference between methods with regard to the results of three-dimensional analysis ($p = 0.10$). The data further validated the measurement accuracy of existing software.

Noble et al. analyzed 120 retrieved liners of eighteen different prosthetic designs. The liners were made of conventional polyethylene. The mean duration of in vivo use was eighty months. Multiple subsurface cracks measuring several millimeters in length were found in 40% of the liners. Evidence of neck-liner impingement was found in association with 32% of the liners. Crack initiation from the region of impingement was observed in association with 70% of the

WHAT'S NEW IN HIP ARTHROPLASTY

liners with cracks. Oxidative changes were present in 90% of the liners with cracks. Impingement and oxidation were therefore the most important factors leading to the formation of cracks within the polyethylene. Holley et al. tested the effect of impingement against highly cross-linked polyethylene in the laboratory. They tested liners that had been irradiated with three different doses (2.8, 10, and 20 Mrad). The cups were mounted in the hip simulator so that impingement resulted during every cycle. The liners were tested for five million cycles. Wear damage was most severe in the liners that had been irradiated at a dose of 20 Mrad, which showed pitting, delamination, and cracking at the impingement sites after a half-million cycles. The damage became more severe as the testing progressed. The authors concluded that impingement may result in accelerated wear even of highly cross-linked polyethylene. It is thus desirable to minimize impingement. This may be accomplished with modifications of implant geometry, the use of larger-diameter femoral heads, and the use of computer guidance systems for more consistent component positioning.

Ceramic

D'Antonio et al. reported an update on ceramic-on-ceramic articulations. The authors described two separate series with slightly different cup design. The mean duration of follow-up was 5.2 years for the first 222 hips and 3.5 years for the second series of 209 hips. No ceramic fractures or bearing failures occurred. The Harris hip scores were similar for both groups and were comparable with those for a series of hips with identical implants with metal-on-polyethylene bearings. Osteolysis was found in 1% of the hips in the first series and in 0% of the hips in the second series. In contrast, osteolysis was present in 18% of the hips with metal-on-polyethylene implants.

Implant fracture is the most feared complication associated with ceramic bearings. Garino et al. reported a 0.01% fracture rate between 2001 and 2003 in a report on more than one million femoral heads that had been inserted into patients. The fracture rate associated with 32-mm heads was lower than that associated with 28-mm heads. Eighty percent of the fractures occurred in the first thirty-six months after surgery. The fracture rate varied from 0% to 0.04% among implants from different manufacturers. Bal et al. reported metal staining in a study of thirteen alumina ceramic femoral heads that had been retrieved after recurrent dislocation or inadvertent impingement against the shell during surgery. The coupling was ceramic-on-ceramic in these implants. The metallic staining was determined to have a chemical composition similar to that of titanium alloy. Evidence of surface anomalies such as uneven wear, cracks, embedded particles, pitting, and deep grooves was present in every head that had been retrieved after recurrent dislocation. The clinical relevance of these findings is unclear. The authors recommended that revision should be a consideration when recurrent dislocation occurs in patients with ceramic-on-ceramic couplings.

Metal-on-Metal

The current generation of metal-on-metal couplings was introduced into clinical application in 1988. Numerous reports and abstracts on clinical outcome, wear measurement, and metal ion analysis have been published over the past fifteen years[10]. This bearing coupling has been used more frequently with the increase in surface arthroplasty and the desire to use larger-diameter femoral heads to reduce dislocation.

Clinical Series

Long, Dorr, and Gendelman[11] reported on the clinical performance of 161 hips that had been treated with the Metasul articulation (Zimmer) performed by a single surgeon. The mean duration of follow-up was 6.5 years (range, two to nine years). This series represents the largest and longest clinical experience in the United States. All cups were modular, with cementless fixation. The mean age of the patients was 55.5 years. With regard to outcome, 98.6% of the patients rated the clinical result as excellent or good with use of a self-assessment questionnaire and 96.5% of the patients were able to walk without limitation. Revision surgery was necessary in six hips (3.7%). One stem was revised because of loosening. Five cups were revised because of liner dissociation due to impingement at three years (one), unexplained pain with the suspicion of possible metal hypersensitivity (two), recurrent dislocation (one), and infection (one). There were no instances of pelvic osteolysis, although radiolucent lines were observed behind 21% of the cups. There was no evidence of femoral osteolysis in the surviving hips. Radiolucent lines were observed around 9.9% of the stems, and calcar resorption was evident around 5.8%. Migaud et al.[12] followed thirty-nine hips with a metal-on-metal coupling for 6.6 years. The patients in that study were part of a prospective trial in which metal-on-metal bearings were compared with ceramic-on-polyethylene bearings. The mean age of the patients was forty years. No implant loosening occurred. The prevalence of osteolysis was significantly lower in the metal-on-metal group (0% compared with 23%, $p < 0.004$). Kim et al.[13] reported the results of sixty-eight cementless metal-on-metal total hip arthroplasties that had been performed in patients younger than fifty years old. The mean duration of follow-up was seven years. The result for 96% of the hips was rated as excellent or good. No stem was loose, whereas two cups were radiographically loose. Femoral osteolysis was present in two hips, and pelvic osteolysis was present in one. The linear wear rate was measured to be 3.4 μm/yr in the retrieved implants.

Proponents of metal-on-metal bearings have cited the advantage of using large-diameter femoral heads, which offer the prospect of reducing dislocation. Cuckler et al.[14] reported the results associated with two series of hip arthroplasties that had been performed with use of two implant designs that were identical except for the articulation; specifically, a 28-mm metal-on-metal coupling was used in seventy-eight hips, and a 38-mm metal-on-metal coupling was used in 616 hips. The

What's New in Hip Arthroplasty

binomial distribution was used to assess the probability that the dislocation rate was significantly different between the two groups on the basis of an assumed risk of early dislocation of 2%. There were no dislocations in the 38-mm group. Binomial analysis revealed that the rate of dislocation was significantly lower for the larger diameter group ($p < 0.001$). The potential risks of metal-ion release and hypersensitivity must be balanced against the lower risk of dislocation.

Wear

One of the major proposed advantages of metal-on-metal couplings is reduced wear, resulting in a lower rate of osteolysis. The wear characteristics of metal-on-metal couplings are influenced by several factors: carbon content, manufacturing process, and diametral clearance. Rieker, Schon, and Kottig[15] described what is perhaps the largest collection of retrieved metal-on-metal couplings, including 608 individual components from 337 revisions. One hundred and seventy-two pairs of these components were available for an analysis of clearance (that is, the surface geometry match between the head and the liner). The in vivo interval varied between one month and twelve years. The authors reported several important findings related to in vivo wear behavior: (1) the mean wear rate in the first year was high (27.8 μm/yr), (2) the mean wear rate following the second year was low (6.2 μm/yr), and (3) regression analysis showed clearance to be the most important variable correlated with the linear wear rate ($p = 0.0005$). Current laboratory and clinical retrieval data on metal-on-metal couplings support the idea that superior wear characteristics are associated with specific features: (1) high carbon content, (2) wrought manufacturing, (3) large diameter, and (4) low clearance.

Metal Ion Release

Heisel et al.[16] evaluated the relationship between activity and serum ion concentrations in a study of seven healthy patients with well-functioning metal-on-metal hip replacements. Activity was monitored with use of a two-dimensional accelerometer for two weeks, with a treadmill test being performed after the first week. The patients were instructed to reduce activities during the first week while increasing activities during the second week. There was no significant change ($p > 0.05$) in the serum levels of cobalt and chromium for a given patient, regardless of activity. There also was no change in the urine chromium level. The authors concluded that it was unnecessary to adjust for patient activities when performing measurements of serum ion levels to monitor patients with metal-on-metal couplings.

Immune Response

Several papers focused on the histological evaluation of periprosthetic tissue retrieved from patients with failed and well-functioning total hip replacements with metal-on-metal couplings[17]. Moreover, several reports presented data on the immune response to metal[18], the induction of cellular necrosis[19], and chromosomal aberrations[20]. Surgeons and research scientists agree on the concerns regarding the potential biological effects of metal debris and metal ions. At the present time, there is no conclusive evidence regarding any adverse clinical impact from metal debris and ion release in patients with metal-on-metal articulations.

The histological appearance of periprosthetic tissue obtained from hips with early-generation metal-on-metal couplings was generally characterized by a mild foreign-body reaction. In 2000, German researchers first reported an unusual perivascular lymphocytic infiltrate with histological features resembling those associated with a type-IV hypersensitivity reaction. Willert et al.[17] evaluated hip tissue from nineteen consecutive patients who underwent aseptic revision of a metal-on-metal total hip replacement. Routine histological and immunochemical staining methods were used. The principal reason for revision was persistent pain with or without implant loosening. The mean time to revision was thirty-three months. Loosening was found in association with seven cups and seven stems. Histological findings included metal debris and lymphocytic infiltrate in every specimen. Eosinophilic granulocytes were found in 40% of the specimens. Fibrin exudates and necrosis were both consistently present. Immunohistochemical analysis confirmed the presence of macrophages and of both T and B lymphocytes. The authors were unable to establish a connection between the immunological response and the quantity of metal debris. It is of special interest to note that no improvement occurred in five patients in whom revision involved an exchange to another metal-on-metal articulation. Clinical improvement was realized in all other patients, who received a different bearing surface coupling. Davies et al.[21] analyzed hip tissue obtained at the time of revision of twenty-five cobalt chromium-on-cobalt chromium, nine cobalt chromium-on-polyethylene, and ten titanium-on-polyethylene total hip arthroplasties. Control tissues were obtained from nine osteoarthritic hips at the time of primary total hip arthroplasty. Perivascular lymphocyte infiltrate was seen in seventeen (68%) of the twenty-five specimens from the metal-on-metal group. Plasma-cell infiltrate was present in ten (40%) of the twenty-five specimens. The authors did not observe any lymphocytic infiltration in the specimens from hips with metal-on-polyethylene articulations. Kim et al.[13] reported on the histological analysis of tissues retrieved from an area of pelvic osteolysis behind a cementless acetabular shell with the metal-on-metal articulation seven years after surgery. These authors also found abundant lymphocytic infiltration, particularly concentrated around the perivascular regions. They did not observe any metal or polyethylene particulate debris on light microscopy.

Hallab et al.[18] analyzed cell-mediated hypersensitivity in a study of thirty-four patients. Nine patients had a metal-on-metal coupling, whereas seven had a metal-on-polyethylene coupling. The other patients were either healthy controls or

WHAT'S NEW IN HIP ARTHROPLASTY

patients who had osteoarthritis and were awaiting surgery. The highest prevalence of reactivity to any metal challenge was in the metal-on-metal group (60%). The lymphocyte proliferation response to a metal challenge was significantly greater in the metal-on-metal group than in the other groups (cobalt, $p < 0.004$; nickel, $p < 0.01$). Most importantly, lymphocyte reactivity was positively correlated with serum metal levels in the metal-on-metal group. While the clinical importance of these data is unclear, the possibility of metal hypersensitivity as a cause of failure cannot be excluded. Chromosomal aberrations, including aneuploidy and translocations, have been documented in patients with failed metal-on-polyethylene couplings. Ladon et al.[20] conducted a prospective study of ninety-five patients who underwent total hip arthroplasty with use of metal-on-metal couplings. Blood samples were obtained before surgery and at six months, one year, and two years after surgery. The serum levels of cobalt and chromium were significantly higher after surgery as long as two years postoperatively ($p < 0.001$). Cytogenic data reflected significantly greater aneuploidy ($p < 0.001$) and translocation ($p < 0.01$) at all time-periods in peripheral blood lymphocytes. While the postoperative-to-preoperative ratios continued to increase with longer follow-up intervals, there was no correlation between serum metal concentration and cytogenetic aberrations. These studies and others have clearly established that there is a biological response to the metal ions from current metal-on-metal bearings. Careful longitudinal monitoring of patients with such bearing couplings must be continued to conclusively determine the clinical relevance of these changes.

Minimal Incision Surgery

Few high-quality peer-reviewed studies on the efficacy and safety of minimal incision techniques have been published. Klein et al. conducted a survey of the members of the Hip Society who were in active clinical practice. Only 18% (eighteen) of 102 respondents made reference to minimal incision techniques on their web sites. Data on the clinical outcome of minimal incision surgery were referenced on only one site. Accelerated rehabilitation was referenced on 7% of the sites. Despite the limited application in most senior surgeons' clinical practices, minimal incision hip arthroplasty has continued to receive intense attention both in the orthopaedic community and in the lay press. Ogonda et al.[22] reported the results of the first large, prospective, randomized, blinded trial of a minimal incision technique. Two hundred and nineteen patients underwent unilateral hybrid total hip arthroplasty through a posterior approach over a six-month period. They were randomized to either a 16-cm (traditional) or 10-cm (minimal incision) technique. The patients were blinded to the surgical techniques. All procedures were performed by a single surgeon who routinely performed >400 total hip arthroplasties each year. Moreover, the surgeon had already performed >300 minimal incision hip arthroplasties with use of the particular surgical technique prior to the beginning of the study. All patients received the same protocol for anesthesia, pain management, and perioperative rehabilitation. There was no difference between the two groups with regard to patient age, body mass index, anesthesia risk (ASA class), preoperative functional status (according to the Harris and Oxford hip scores), or general health status (according to the WOMAC and SF-12 instruments) ($p > 0.02$ for all categories). Outcome measures included pain assessment with use of a visual analog scale and the recording of analgesic use. Moreover, physical function was quantified with gait analysis. The estimated blood loss during surgery was significantly lower in the minimal incision group ($p = 0.03$); this was the only significant difference between the groups. Analysis of a subgroup of patients who had a body mass index of >35 demonstrated increased operative time regardless of the surgical approach used. There was no difference between the groups with regard to pain scores or the use of analgesics in the first thirty-six hours after surgery ($p > 0.22$). At six weeks after surgery, there was no difference between the groups with regard to any of the functional or general-health outcome measures ($p > 0.33$). There also was no difference between the groups with regard to gait or stair-climbing ability ($p > 0.22$). Radiographic evaluation demonstrated no difference in cup or stem position or in cementing grade. There was no difference with regard to complications. Finally, there was no difference with regard to the length of hospital stay ($p = 0.94$).

Other surgeons have reported significantly shorter hospital stays (less than twenty-four hours), accelerated improvement of function, and reduced pain in association with minimal-incision total hip arthroplasty[23]. Multiple factors other than the surgical approach (i.e., anesthesia, pain management, physical therapy protocol, and patient selection) could account for the different data. Swanson reported on his experience with the use of a posterior minimal incision approach for the management of 1000 patients over a five-year period. The mean operative time was fifty-three minutes, and the mean blood loss was 307 mL. Despite this relatively low blood loss, 40% of the patients required at least one unit of blood transfusion. The mean length of the incision was 9.6 cm (range, 7.0 to 15.0 cm). The mean length of stay in the hospital was 3.8 days. Complications included infection (prevalence, 1%), skin necrosis (prevalence, 1%), and nerve palsy (prevalence, 0.8%). The most common complication was dislocation (prevalence, 3.1%). There were no data on femoral fractures. After a mean duration of follow-up of thirty-seven months, all stems were stable and six cups were loose. Matta reported on his experience with the performance of 386 consecutive primary total hip arthroplasties with use of an anterior minimal incision technique. This technique requires traction with use of a specialized table. The mean operative time was 1.5 hours. The mean length of stay in the hospital was four days. There were three fractures of the trochanter, two ankle fractures from traction, one fracture of the calcar,

WHAT'S NEW IN HIP ARTHROPLASTY

and one fracture of the acetabulum. The author provided no functional outcome data and no long-term clinical or radiographic follow-up data.

Computer-assisted-surgery techniques have received increasing attention, particularly when used in conjunction with minimal-incision surgery. Wixson and McDonald used a computer guidance system in conjunction with a posterior minimal incision technique in eighty-two hips. The authors compared the cup position measurements for this group with those for a group of control patients in whom the procedures were performed with use of a conventional posterior approach. There was no difference between the groups with regard to cup abduction and anteversion angles. However, the variability from patient to patient was significantly less in the computer guidance group ($p = 0.01$). These and other previously presented data support the ability to decrease the variability of cup position when a computer guidance system is used. There were no dislocations in either group.

The enthusiasm for minimal-incision hip arthroplasty was initiated by the surgeons who introduced the two-incision surgical approach. There has been controversy with regard to the proposed clinical efficacy, safety, and marketing of this technique. Bal et al. reported short-term (six-month) results of eighty-nine consecutive hip arthroplasties that had been performed with use of the two-incision technique as proposed by Mears and Berger. Reoperation was necessary for nine patients (10%). Complications included two femoral fractures, one dislocation, two wound infections, and four episodes of implant loosening. Injury to the lateral femoral cutaneous nerve occurred in 25% of the patients; all of these injuries resolved. There were no reported cases of sciatic nerve palsy, but there was one case of femoral nerve palsy. Pagnano et al. compared the results of eighty consecutive hip replacements that had been performed with use of the two-incision technique with those of 160 consecutive hip replacements that had been performed with use of a conventional incision technique. The rate of early complications was 14% (eleven of eighty) in the minimal incision group, compared with 3.8% in the conventional incision group. In the minimal incision group, there were four intraoperative and three postoperative femoral fractures and there was one episode each of dislocation, stem subsidence, and deep infection. One of the most important findings was that femoral fractures continued to occur even after the surgeon had performed more than sixty procedures.

Surgeons and engineers have continued to develop new surgical approaches, retractors, instrumentation, computer guidance systems, multimodal pain-management protocols, and accelerated rehabilitation programs in the hope of improving the clinical outcome following total hip arthroplasty, regardless of the size of the skin incision. It is hoped that further refinement of the techniques and instrumentation will enable surgeons to perform minimal-incision total hip arthroplasty with reproducible efficacy and minimal complications.

Complications

Surgeon Volume

Surgeon volume has been cited as a factor affecting the variations in complications[23]. Sharkey et al.[24] reviewed the outcome of 1000 hip arthroplasties (including 786 primary procedures and 214 revisions) that had been performed over a one-year period at a high-volume tertiary joint arthroplasty center. The combined rate of orthopaedic and medical complications in the first six months was 7.9% for primary procedures and 16.5% for revision procedures. The greatest differences between the primary and revision procedures were the rates of infection and cardiac problems. The authors concluded that there is a baseline complication rate for total hip arthroplasty, regardless of volume.

Thromboembolic Disease

It is agreed that prophylaxis against venous thromboembolism is required following total hip arthroplasty. Substantial controversies remain with regard to which method is the safest and most effective. The newest form of prophylaxis is the use of an oral direct thrombin inhibitor. Extensive phase-3 clinical trials of one such direct thrombin inhibitor (ximelagatran) have been performed in patients managed with hip or knee arthroplasty. Ximelagatran was more efficacious than warfarin in patients managed with knee arthroplasty ($p = 0.003$)[25], but it was not superior to low-molecular-weight-heparin in patients managed with hip arthroplasty. There was no difference between warfarin and low-molecular-weight heparin with regard to bleeding complications. A registration request for this agent was rejected by the Food and Drug Administration in 2004, principally on the basis of concerns related to associated abnormalities seen in liver-function studies in treated patients.

Eriksson et al.[26] reported the phase-2 clinical trial data on another new oral direct thrombin inhibitor (dabigatran). The study included nearly 2000 patients managed with hip or knee arthroplasty. The administration of dabigatran was started within one to four hours after surgery. The comparator was low-molecular-weight-heparin (enoxaparin), which was started before surgery and was continued at a dose of 40 mg/day after surgery. The overall rate of thrombosis was significantly lower in patients receiving dabigatran (range, 13.1% to 16.6%) than in those receiving enoxaparin (24%) ($p = 0.04$). There was, however, a higher rate of bleeding complications, particularly with higher doses, among patients receiving dabigatran ($p = 0.05$). The efficacy and safety of this agent are currently being tested in phase-3 clinical trials.

Controversies exist with regard to the necessity of extended prophylaxis. Pellegrini et al. reported data for >1800 patients. The protocol involved the administration of adjusted-dose warfarin (with a target international normalized ratio of 1.5 to 2.0) after surgery and a screening venogram at the time of discharge. No further prophylaxis was continued if the venogram was negative. Adjusted-dose warfarin was continued for three months if the venogram was positive for calf

WHAT'S NEW IN HIP ARTHROPLASTY

thrombosis and for six months if it was positive for proximal thigh thrombosis. The thrombosis rate was 14.7% for patients managed with hip replacement and 41.3% for patients managed with knee replacement. The rate of readmission to the hospital because of symptomatic thromboembolism was 0.82% for patients with a positive venogram (who had been managed with continued administration of adjusted-dose warfarin), compared with 1.9% for those with a negative venogram (who had been managed with discontinuation of warfarin). In the hip replacement group, a higher rate of thromboembolism was noted after warfarin was discontinued (0.7% vs. 1.8%, $p < 0.01$). No such difference was noted in the knee replacement group. While adjusted-dose warfarin was less effective than some of the newer anticoagulants, extended prophylaxis with use of this agent did reduce symptomatic thromboembolism following total hip arthroplasty.

Salvati et al. reported a significantly higher prevalence of heritable and developmental thrombophilic abnormalities in patients with documented venous thromboembolic disease following total hip arthroplasty. The investigators quantified numerous genetic mutations and serological markers known to be associated with thrombophilia in forty-three patients (twenty with proximal deep-vein thrombosis as documented with magnetic resonance venography and twenty-three with symptomatic pulmonary embolism as documented with a ventilation-perfusion lung scan). These patients were matched to a group of control patients who underwent total hip arthroplasty but did not have a known venous thromboembolic event. Significant differences between the two groups were found with regard to antithrombin deficiency ($p = 0.02$), protein-C deficiency ($p = 0.02$), and prothrombin gene mutation ($p = 0.0037$). The likelihood of having at least one of these three findings was significantly more common in patients who had a thromboembolic event ($p < 0.0001$). A model constructed with use of these parameters for the prediction of thromboembolism demonstrated a sensitivity of 50% but a specificity of 93%. It is hoped that analysis for thrombophilia can assist in the stratification of risk to modify prophylaxis following hip arthroplasty in the future.

Dislocation

Recurrent dislocation has now become the third most frequent cause of revision surgery, resulting in an intense focus on surgical technique, large-diameter articulations, increased femoral stem offset, and rehabilitation protocols. One of the most common methods with which to address dislocation is the use of a constrained acetabular liner. Callaghan et al.[27], in a study of thirty-one hips, reported the results of cementing a constrained liner into a well-fixed acetabular shell. The mean duration of follow-up was 3.9 years. Two liners failed: one because of debonding between the liner and the cement, and the other because of failure of the capturing mechanism. No shell was loose. This particular liner design and surgical technique can be a successful option in certain difficult cases. Berend et al. reported on a very large series of hips that had been treated with constrained liners. The surgeons inserted 720 constrained liners over a seven-year period, with 91.4% of the liners being inserted at the time of revision or conversion surgery. The rate of survival of the liner was only 57.9%. Despite the constraint, the rate of dislocation was 17.5% overall and 28.5% in the subgroup of patients who had had a previous dislocation. Aseptic revision for loosening was necessary in 15% of the hips. Other major complications included infection (prevalence, 6.2%) and periprosthetic fractures (prevalence, 3%). These data reflect the need for further improvements in implant design and surgical technique in order to address this common clinical problem.

Infection

Di Cesare et al. evaluated the efficacy of using serum interleukin-6 levels as a marker for infection in a study of fifty-eight patients (seventeen of whom had an infection and forty-one of whom did not). Significantly elevated levels were found in the patients with infection ($p < 0.01$). Elevated levels were found to have a sensitivity of 100%, a specificity of 95%, a positive predictive value of 89%, a negative predictive value of 100%, and an accuracy of 97%. This test may be of value in some cases, particularly for excluding infection as a cause of a suboptimal clinical result. Selgrath et al. performed polymerase chain reaction analysis on the synovial fluid from 157 joints in patients who were scheduled to undergo revision hip or knee arthroplasty. A discordant result between the results of routine bacterial culture and polymerase chain reaction was found in twenty-four samples; specifically, ten samples demonstrated a positive result on culture and a negative result on polymerase chain reaction whereas fourteen samples demonstrated a negative result on culture and a positive result on polymerase chain reaction. No clinical outcome data were provided for these patients. The authors recommended changes in the protocol to improve the sensitivity and specificity of this test in the diagnosis of arthroplasty infections.

A two-stage reimplantation protocol has been used for the treatment of deep infection around joint replacements for more than two decades. Goldberg et al. reported on thirty-one consecutive patients who had been managed with a two-stage protocol that included removal of the implants, administration of antibiotics for six weeks, and reimplantation with use of cementless fixation. There were no infections following reimplantation. One patient had a late infection with a different organism sixty-six months after reimplantation. Two cups and one stem were revised because of aseptic loosening. Marculesca et al. reviewed the results of a two-stage protocol in a study of forty-three patients who had infections with methicillin-resistant organisms. The mean duration of follow-up was thirty-three months. Infection recurred in 16% of the patients, with six of the seven reinfections being caused by the same organism. Moreover, 7% of the patients had positive histopathological studies at the time of reimplantation. These pa-

WHAT'S NEW IN HIP ARTHROPLASTY

tients were managed with chronic suppressive therapy, and none of them had development of a clinically apparent infection.

Practice Management

Wound Drain

The use of wound-suction drains following total hip arthroplasty is controversial. Parker et al.[28] conducted a meta-analysis evaluating the efficacy of using and not using wound drains following total hip and total knee arthroplasty. The investigators selected eighteen prospective, randomized studies involving 3495 patients with 3689 wounds. There was no difference between patients who had been managed with a drain and those who had not with respect to the occurrence of wound infection, hematoma, or reoperation for wound complications. There was also no difference with respect to pain, thromboembolism, or range of motion. The only significant difference was a greater rate of transfusion among patients who had been managed with a drain ($p < 0.02$).

Blood Transfusion

Limiting allogeneic blood transfusion is desirable because it would reduce the potential for viral disease transmission as well as cost. Pierson et al.[29], in a study of patients undergoing total hip and total knee arthroplasty, presented a blood-conservation algorithm, based on a mathematical formula, that was used to calculate the projected lowest hemoglobin level after surgery. If this level was <7.0 g/dL, the patient was offered preoperative erythropoietin treatment. No intraoperative or postoperative blood salvage was done. Two groups were retrospectively identified: the first group comprised 433 patients for whom the algorithm was implemented, and the second group comprised sixty-seven patients for whom the algorithm was not implemented for a variety of reasons (primarily the patient's insistence on preoperative autologous or donor-directed blood donation). The overall transfusion rate was 2.1% among the patients for whom the algorithm was implemented (2.8% among those managed with hip replacement and 1.4% among those managed with knee replacement), compared with 16.4% among those for whom it was not implemented ($p < 0.0001$). The rate of major complications in the first ninety days was 1.4%; the complications included three deaths (two of which were due to a myocardial infarction and one of which was due to a cerebral infarct), three nonfatal myocardial infarctions, and one pulmonary embolism. There was no association between these complications and anemia.

Pharmacological Agents and Bone-Remodeling

The adverse effects of nonsteroidal anti-inflammatory drugs on fracture repair and bone-remodeling have been extensively studied. Andersen et al. analyzed the revision rate in patients in the Danish Hip Arthroplasty Registry who had received nonsteroidal anti-inflammatory agents after total hip arthroplasty. More than 43,000 hips were entered into the Registry between 1995 and 2003. In 7185 of these cases, the patient received nonsteroidal anti-inflammatory drugs during the perioperative period. The revision rate among patients who had been managed with a cementless replacement and nonsteroidal anti-inflammatory drugs was higher than that among patients who had not received nonsteroidal anti-inflammatory drugs (relative risk, 3.09). In contrast, the revision rate among patients who had been managed with a cemented hip replacement and nonsteroidal anti-inflammatory drugs was lower than that among patients who had not received nonsteroidal anti-inflammatory drugs, (possibly because of a protective effect). The investigators recommended avoiding the use of nonsteroidal antiinflammatory medications after surgery if cementless fixation was used. Lionberger and Noble conducted a prospective, placebo-controlled, double-blind study investigating the effect of a cyclooxygenase-2 inhibitor on bone-remodeling following cementless total hip arthroplasty. Forty-nine patients were randomized to receive either placebo or celecoxib (200 mg/day). Treatment was continued for six weeks. There was no difference between the groups with regard to the bone mineral density around the implants at three or six months after surgery ($p = 0.56$). There also was no difference with regard to bone density in the femoral Gruen zones. The concentration of N-telopeptide (a marker of bone turnover) was significantly higher in the celecoxib group at six weeks ($p = 0.004$) but not at twelve weeks ($p = 0.23$). No adverse changes were observed on regular hip radiographs with regard to signs of osseointegration. The authors concluded that there were no adverse effects in association with the administration of low-dose celecoxib for six weeks following cementless total hip arthroplasty.

Periprosthetic femoral bone loss due to stress transfer is generally greater in association with cementless implants and in Gruen zone 7 (the calcar region). Decreasing periprosthetic bone loss is important because more patients are receiving cementless total hip replacements and because the implants remain in place for longer durations. Arabmotlagh et al. conducted a prospective, randomized, placebo-controlled study of fifty-one patients undergoing cementless hip arthroplasty. One group received a placebo for two months, whereas the other group received a bisphosphonate (alendronate). The bisphosphonate group was then further studied by randomization of the patients to continued treatment with the bisphosphonate at a lower dose for either two or four additional months. Patients who were managed with the bisphosphonate for six months still had bone loss in zone 7 ($p = 0.05$) but had increased bone mineral density in zones 4 and 5 ($p = 0.01$). The marker of bone resorption (C-terminal telopeptide of type-1 collagen) decreased for as long as six months in association with bisphosphonate treatment. One marker of bone formation (bone-specific alkaline phosphatase) increased, whereas another (osteocalcin) remained unchanged in association with bisphosphonate treatment. Bhandari et al.[30] con-

WHAT'S NEW IN HIP ARTHROPLASTY

ducted a meta-analysis of the publications from 1989 to 2003 to evaluate the effect of bisphosphonates on periprosthetic bone mineral density following total hip arthroplasty. Six studies, with a total of 290 patients, met the inclusion criteria. Bisphosphonate treatment was associated with significantly less bone loss at three months ($p < 0.01$), six months ($p < 0.001$), and twelve months ($p = 0.03$). The effect was more pronounced in hips with cement fixation compared with those with cementless fixation. The major limitations of these studies were that they only evaluated short-term effect and that there was no correlation with functional outcome or revision rate. The current evidence regarding the beneficial effects of bisphosphonates on periprosthetic bone loss should be interpreted with caution until more data are generated in larger populations of patients and there is longer follow-up involving correlation with clinical and radiographic parameters.

Joint Registry

The North American Outcomes Registry for Total Hip and Knee Replacement was initiated in 1995. Experience with this registry can be invaluable to surgeons and researchers who are working on the American Joint Replacement Registry pilot program sponsored by the American Academy of Orthopaedic Surgeons. Callaghan et al. reported on patient enrollment, follow-up data, and costs. One thousand two hundred and nineteen surgeons registered between 1995 and 2001; however, only 489 (40%) actually entered patient data. Surgeon enrollment decreased from 489 in 1995 to 133 in 2001. Nearly 39,000 patients were entered into the Registry during this seven-year period. There was a decrease in patient volume from 1997 to 2001 for both total hip arthroplasty (from 1500 to 1200) and total knee arthroplasty (from 3000 to 1600). The rate of completion of the one-year follow-up data form was 24% in 1998 and 30% in 2001. However, the rate of completion of the two-year follow-up form was 6% in 1998 and 11% in 2001. The cost for maintaining this registry was approximately $750,000 annually. There is a need to refine the reporting methodology in order to achieve higher compliance rates for future registry initiatives. Moreover, the goals of a registry must be clearly defined in order to achieve meaningful data collection.

Cost Analysis

Rising health-care costs and diminishing health-care resources have forced orthopaedic surgeons and other health-care professionals to develop innovative methods to continue to provide cost-efficient and high-quality care to our patients. The financial burden will continue to escalate with the projected increase in the volume of surgery. One of the most challenging areas of focus is in revision total hip arthroplasty.

Antoniou et al.[31] conducted a relatively simple analysis to compare the in-hospital cost of primary total hip arthroplasty in three tertiary teaching hospitals each in Canada (940 patients) and in the United States (739 patients). These were relatively large hospitals with bed capacities ranging from 500 to 850. All procedures were done between 1999 and 2001. The cost figures were not adjusted for inflation. Data were extracted from the Transition cost-accounting system. The total cost for a given patient involved direct cost (personnel and supplies) and overhead cost (administration and housekeeping). Direct cost represented 68.9% of the total cost in Canada and 62.9% of the total cost in the United States. The mean total cost was dramatically different between the two countries: $6766 in Canada and $13,339 in the United States ($p < 0.0001$). The mean length of stay was significantly ($p < 0.0001$) longer in Canada (7.2 days) than in the United States (4.2 days). There was no difference in terms of complication rates. Data on implant cost were available only from one hospital each in Canada ($1695) and in the United States ($8017). The authors concluded that cost-containment efforts in the United States should be focused on reducing implant cost.

Crowe, Sculco, and Kahn presented a hospital cost and reimbursement analysis of revision hip arthroplasty[32]. The investigators randomly selected fifty-one revisions that had been done between 1995 and 1999 at a tertiary joint arthroplasty hospital. The mean length of stay in the hospital was 7.4 days. The mean operative time was three hours and forty minutes, and the mean length of stay in the recovery room/intensive care unit was fourteen hours and twenty minutes. Approximately equal numbers of patients received cemented and cementless stems. A majority of the cup revisions were done with use of cementless fixation. Bone-grafting was necessary for 59% of the acetabulae and 31% of the femora. Major medical complications occurred in 18% of the patients. Patients younger than sixty-five years of age had fewer complications than older patients did (prevalence, 10% compared with 23%). The mean cost per case was $21,224 (range, $10,165 to $44,602). There was a significant difference in cost between procedures that involved bone-grafting ($28,097) and those that did not ($17,245) ($p = 0.004$). There was also a significant difference between older patients (that is, patients who were more than sixty-five years old) and younger patients ($23,417 compared with $18,309; $p = 0.016$). The mean reimbursement to the hospital was $15,822, reflecting a loss of $5402 per case. The mean reimbursement for Medicare patients was less than that for non-Medicare patients ($14,800 compared with $17,176). Every Medicare patient incurred a loss, and the mean loss was $8617 per case. Bozic et al.[5] evaluated the clinical, demographic, and economic data associated with 491 consecutive unilateral primary and revision total hip arthroplasties performed at a single institution in a three-year period (January 2000 to December 2003). There was a significant ($p < 0.0001$) difference in the severity-of-illness score between patients managed with primary and revision procedures. The intraoperative blood loss ($p < 0.0001$), operative time ($p < 0.0001$), and length of hospital stay ($p < 0.0005$) were also significantly greater in the revision group. There was no difference between groups with regard to the overall complication

WHAT'S NEW IN HIP ARTHROPLASTY

rate ($p = 0.072$). However, there was a higher rate of readmission within ninety days in the revision group ($p = 0.05$). The mean cost of revision arthroplasty (in 2003 dollars) was significantly greater than that of primary arthroplasty ($31,341 ± $11,989 compared with $24,170 ± $6,700; $p < 0.0001$). Moreover, there was a significant difference in every cost category (implant, operating room, post-anesthesia care unit, nursing, radiology, laboratory, and pharmacy). Multivariate regression analysis demonstrated that higher cost was related to greater severity of illness and to the presence of bone deficiencies in the acetabulum and femur.

Bozic et al., at the 2004 meeting of the American Association of Hip and Knee Surgeons, presented additional economic data from a study of 4533 total hip arthroplasties that had been performed at three centers over the same three-year period (from 2000 to 2003). The study included 3048 primary and 1485 revision procedures. The operative time ($p < 0.001$), utilization of bone graft ($p < 0.0001$), length of hospital stay ($p < 0.0001$), and utilization of extended-care facilities after discharge ($p < 0.0001$) were all significantly greater in the revision group. Hospital costs relative to primary hip arthroplasty (100%) were higher for procedures involving revision of both components (138%), isolated revision of the stem (129%), and isolated revision of the cup (101%) ($p < 0.0001$). This disparity and the expected dramatic increase (>12% to 15% annually) in revision procedures will undoubtedly put an enormous burden on the health-care delivery system in the United States in the years to come.

Evidence-Based Orthopaedics

The editorial staff of *The Journal* reviewed a large number of recently published research studies related to the musculoskeletal system that received a Level of Evidence grade of I. Over 100 medical journals were reviewed to identify these articles, which all have high-quality study design. In addition to articles published previously in this journal or cited already in this update, six level-I articles were identified that are relevant to total hip arthroplasty. A list of those titles is appended to this review after the standard bibliography. We have provided a brief commentary about each of the articles to help guide your further reading, in an evidence-based fashion, in this subspecialty area.

Future Meetings and Educational Courses

The major conferences that focus on peer-reviewed scientific data presentations are the annual meeting of the American Association of Hip and Knee Surgeons (to be held in Dallas, Texas, on November 4, 5, and 6, 2005), the annual meeting of The Hip Society (to be held on Specialty Day in New Orleans, Louisiana, on March 11, 2006), the annual meeting of the American Academy of Orthopaedic Surgeons (to be held in New Orleans, Louisiana, from March 8 to 12, 2006), and the annual meeting of the Orthopaedic Research Society (to be held in New Orleans, Louisiana, from March 5 to 8, 2006). The American Academy of Orthopaedic Surgeons generally offers two or three continuing medical education courses annually. Finally, peer-reviewed scientific presentations also are given at the annual meetings of the regional orthopaedic societies such as the Eastern, Mid-American, Southern, and Western Orthopaedic Associations.

IN MEMORIAM: It is with sincere regret and sadness that we bring the news of death of two members of the Hip Society during the past year. Dr. Carl Nelson and Dr. Marvin Meyers both were important contributors to the mission and vision of reconstructive hip surgery.

Michael H. Huo, MD
Nathan F. Gilbert, MD
Department of Orthopedic Surgery, University of Texas Southwestern Medical School, 5323 Harry Hines Boulevard, Dallas, TX 75390-8883.
E-mail address for M.H. Huo: michael.huo@utsouthwestern.edu

The authors did not receive grants or outside funding in support of their research or preparation of this manuscript. They did not receive payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity. No commercial entity paid or directed, or agreed to pay or direct, any benefits to any research fund, foundation, educational institution, or other charitable or nonprofit organization with which the authors are affiliated or associated.

doi:10.2106/JBJS.E.00474

References

1. Amstutz HC, Beaule PE, Dorey FJ, Le Duff MJ, Campbell PA, Gruen TA. Metal-on-metal hybrid surface arthroplasty: two to six-year follow-up study. J Bone Joint Surg Am. 2004;86:28-39.

2. Amstutz HC, Campbell PA, Le Duff MJ. Fracture of the neck of the femur after surface arthroplasty of the hip. J Bone Joint Surg Am. 2004;86:1874-7.

3. Beaule PE, Lee JL, Le Duff MJ, Amstutz HC, Ebramzadeh E. Orientation of the femoral component in surface arthroplasty of the hip. A biomechanical and clinical analysis. J Bone Joint Surg Am. 2004;86:2015-21.

4. Silva M, Lee KH, Heisel C, Dela Rosa MA, Schmalzried TP. The biomechanical results of total hip resurfacing arthroplasty. J Bone Joint Surg Am. 2004;86:40-6.

5. Bozic KJ, Katz P, Cisternas M, Ono L, Ries MD, Showstack J. Hospital resource utilization for primary and revision total hip arthroplasty. J Bone Joint Surg Am. 2005;87:570-6.

6. Parvizi J, Sim FH. Proximal femoral replacements with megaprostheses. Clin Orthop Relat Res. 2004;420:169-75.

7. Berend KR, Lombardi AV Jr, Mallory TH, Adams JB, Dodds KL. Total femoral arthroplasty for salvage of end-stage prosthetic disease. Clin Orthop Relat Res. 2004;427:162-70.

8. Bradford L, Baker DA, Graham J, Chawan A, Ries MD, Pruitt LA. Wear and surface cracking in early retrieved highly cross-linked polyethylene acetabular liners. J Bone Joint Surg Am. 2004;86:1271-82.

9. Shen FW, McKellop H. Surface-gradient cross-linked polyethylene acetabular cups: oxidation resistance and wear against smooth and rough femoral balls. Clin Orthop Relat Res. 2005;430:80-8.

10. Dumbleton JH, Manley MT. Metal-on-metal total hip replacement: what does the literature say? J Arthroplasty. 2005;20:174-88.

WHAT'S NEW IN HIP ARTHROPLASTY

11. Long WT, Dorr LD, Gendelman V. An American experience with metal-on-metal total hip arthroplasties: a 7-year follow-up study. J Arthroplasty. 2004;19(8 Suppl 3):29-34.

12. Migaud H, Jobin A, Chantelot C, Giraud F, Laffargue P, Duquennoy A. Cementless metal-on-metal hip arthroplasty in patients less than 50 years of age: comparison with a matched control group using ceramic-on-polyethylene after a minimum 5-year follow-up. J Arthroplasty. 2004;19(8 Suppl 3):23-8.

13. Kim SY, Kyung HS, Ihn JC, Cho MR, Koo KH, Kim CY. Cementless Metasul metal-on-metal total hip arthroplasty in patients less than fifty years old. J Bone Joint Surg Am. 2004;86:2475-81.

14. Cuckler JM, Moore KD, Lombardi AV Jr, McPherson E, Emerson R. Large versus small femoral heads in metal-on-metal total hip arthroplasty. J Arthroplasty. 2004;19(8 Suppl 3):41-4.

15. Rieker CB, Schon R, Kottig P. Development and validation of a second-generation metal-on-metal bearing: laboratory studies and analysis of retrievals. J Arthroplasty. 2004;19 (8 Suppl 3):5-11.

16. Heisel C, Silva M, Skipor AK, Jacobs JJ, Schmalzried TP. The relationship between activity and ions in patients with metal-on-metal bearing hip prostheses. J Bone Joint Surg Am. 2005;87:781-7.

17. Willert HG, Buchhorn GH, Fayyazi A, Flury R, Windler M, Koster G, Lohmann CH. Metal-on-metal bearings and hypersensitivity in patients with artificial hip joints. A clinical and histomorphological study. J Bone Joint Surg Am. 2005;87:28-36.

18. Hallab NJ, Anderson S, Caicedo M, Skipor A, Campbell P, Jacobs JJ. Immune responses correlate with serum-metal in metal-on-metal hip arthroplasty. J Arthroplasty. 2004;19(8 Suppl 3):88-93.

19. Huk OL, Catelas I, Mwale F, Antoniou J, Zukor DJ, Petit A. Induction of apoptosis and necrosis by metal ions in vitro. J Arthroplasty. 2004;19(8 Suppl 3):84-7.

20. Ladon D, Doherty A, Newson R, Turner J, Bhamra M, Case CP. Changes in metal levels and chromosome aberrations in the peripheral blood of patients after metal-on-metal hip arthroplasty. J Arthroplasty. 2004;19(8 Suppl 3):78-83.

21. Davies AP, Willert HG, Campbell PA, Learmonth ID, Case CP. An unusual lymphocytic perivascular infiltration in tissues around contemporary metal-on-metal joint replacements. J Bone Joint Surg Am. 2005;87:18-27.

22. Ogonda L, Wilson R, Archbold P, Lawlor M, Humphreys P, O'Brien S, Beverland D. A minimal-incision technique in total hip arthroplasty does not improve early postoperative outcomes. A prospective, randomized, controlled trial. J Bone Joint Surg Am. 2005;87:701-10.

23. Huo MH, Muller MS. What's new in hip arthroplasty. J Bone Joint Surg Am. 2004;86:2341-53.

24. Sharkey PF, Shastri S, Teloken MA, Parvizi J, Hozack WJ, Rothman RH. Relationship between surgical volume and early outcomes of total hip arthroplasty: do results continue to get better? J Arthroplasty. 2004;19:694-9.

25. Francis CW, Berkowitz SD, Comp PC, Lieberman JR, Ginsberg JS, Paiement G, Peters GR, Roth AW, McElhattan J, Colwell CW Jr; EXULT A Study Group. Comparison of ximelagatran with warfarin for the prevention of venous thromboembolism after total knee replacement. N Engl J Med. 2003;349:1703-12.

26. Eriksson BI, Dahl OE, Buller HR, Hettiarachchi R, Rosencher N, Bravo ML, Ahnfelt L, Piovella F, Stangier J, Kalebo P, Reilly P; BISTRO II Study Group. A new oral direct thrombin inhibitor, dabigatran etexilate, compared with enoxaparin for prevention of thromboembolic events following total hip or knee replacement: the BISTRO II randomized trial. J Thromb Haemost. 2005;3:103-11.

27. Callaghan JJ, Parvizi J, Novak CC, Bremner B, Shrader W, Lewallen DG, Johnston RC, Goetz DD. A constrained liner cemented into a secure cementless acetabular shell. J Bone Joint Surg Am. 2004;86:2206-11.

28. Parker MJ, Roberts CP, Hay D. Closed suction drainage for hip and knee arthroplasty. A meta-analysis. J Bone Joint Surg Am. 2004;86:1146-52.

29. Pierson JL, Hannon TJ, Earles DR. A blood-conservation algorithm to reduce blood transfusions after total hip and knee arthroplasty. J Bone Joint Surg Am. 2004;86:1512-8.

30. Bhandari M, Bajammal S, Guyatt GH, Griffith L, Busse JW, Schunemann H, Einhorn TA. Effect of bisphosphonates on periprosthetic bone mineral density after total joint arthroplasty. A meta-analysis. J Bone Joint Surg Am. 2005;87:293-301.

31. Antoniou J, Martineau PA, Filion KB, Haider S, Zukor DJ, Huk OL, Pilote L, Eisenberg MJ. In-hospital cost of total hip arthroplasty in Canada and the United States. J Bone Joint Surg Am. 2004;86:2435-9.

32. Crowe JF, Sculco TP, Kahn B. Revision total hip arthroplasty: hospital cost and reimbursement analysis. Clin Orthop Relat Res. 2003;413:175-82.

Evidence-Based Articles Related to Total Hip Arthroplasty

Sanders C, Donovan JL, Dieppe PA. Unmet need for joint replacement: a qualitative investigation of barriers to treatment among individuals with severe pain and disability of the hip and knee. *Rheumatology (Oxford)*. 2004;43:353-7.

Wide variations exist in terms of access to joint arthroplasty. This is especially a problem in public health systems such as in the United Kingdom. The authors identified twenty-seven patients who had high levels of hip and/or knee pain and disability due to arthritis. These patients were interviewed initially and again five years later. Identical measures of health status were used during both time-periods. The mean age was seventy-six years. Only 50% of the patients were referred to a specialist in orthopaedics or rheumatology. Three types of barriers were identified: (1) the patient's own reluctance to seek treatment from a specialist, (2) the primary-care physician's reluctance to refer the patient, and (3) the perception of the ineffectiveness and risks of joint arthroplasty. The authors concluded that there was a need to improve the education of primary-care physicians and patients with regard to the indications for, and the efficacy and risks of, joint arthroplasty. These barriers may not be as pronounced in the United States.

Temmerman OP, Raijmakers PG, David EF, Pijpers R, Molenaar MA, Hoekstra OS, Berkhof J, Manoliu RA, Teule GJ, Heyligers IC. A comparison of radiographic and scintigraphic techniques to assess aseptic loosening of the acetabular component in a total hip replacement. *J Bone Joint Surg Am*. 2004;86;2456-63.

Cup fixation was evaluated in eighty-six consecutive hips with use of plain radiographs, bone scintigraphy, subtraction arthrography, and nuclear arthrography. Seventy percent of the cups were cemented, and 30% were cementless. Plain radiography was the best single method, with a specificity of 85% and a sensitivity of 85%. The interobserver correlation coefficient was 0.37. Multivariate analysis demonstrated the efficacy of multimodal evaluation. Subtraction arthrography and bone scintigraphy both had a significant predictive value for cup loosening when used in conjunction with plain radiography ($p < 0.05$). These methods were especially valuable if the studies were negative as 95% of the stable cups were in hips that had normal radiographs and normal adjunct studies. A negative study (specificity) is more valuable to the clinician in deciding whether surgery is indicated.

Karachalios T, Tsatsaronis C, Efraimis G, Papadelis P, Lyritis G, Diakoumopoulos G. The long-term clinical relevance of calcar atrophy caused by stress shielding in total hip arthroplasty: a 10-year, prospective, randomized study. *J Arthroplasty*. 2004;19:469-75.

Eighty women with osteoarthritis of the hip were randomized into four groups, each of which received a different stem design inserted without cement. The mean age was seventy years. One type of stem was made of cobalt-chromium alloy, and the other three types were made of titanium alloy. The stems had four different surface textures: macrointerlock, hydroxyapatite coating, proximal coating with beads, and matte surface. There were four different cross-sectional geometries. In all patients, progressive bone loss in the calcar region (Gruen zone 7) was evident as much as two years postoperatively, with the reduction in bone density values ranging from 8% to 24%. The reduction from the baseline value was significant in association with three of the four stem designs. A pattern of progressive recovery was observed in all hips. The least change in bone mineral density was observed in hips that had received a stem with a tapered geometry and a hydroxyapatite coating. There was no difference among the groups with regard to the Harris hip score. One of the limitations of the study was that the patients were relatively old. The pattern of bone loss may be different in younger patients and after a longer duration in situ. Differences in bone loss may be associated with different stem designs, wear at the articulation, and other clinical parameters.

Gonzalez Della Valle A, Slullitel G, Vestri R, Comba F, Buttaro M, Piccaluga F. No need for routine closed suction drainage in elective arthroplasty of the hip: a prospective randomized trial in 104 operations. *Acta Orthop Scand.* 2004;75:30-3.

What's New in Hip Arthroplasty

The authors randomized 104 patients undergoing unilateral total hip arthroplasty to receive or not to receive a drain. Hybrid fixation was used in 40% of the procedures, and cementing of all components was performed in 60% of the procedures. All procedures were done through a posterior approach with the patient under hypotensive epidural anesthesia. Thromboembolic prophylaxis involved intraoperative administration of heparin followed by administration of aspirin for three weeks. The mean amount of drain collection was 290 mL. There was no difference in blood transfusion rates.

There was, however, a significant reduction of hematocrit ($p = 0.03$) and a longer length of stay ($p = 0.01$) in the group of patients who had received a drain. There was no difference between the groups with regard to the prevalence of draining wounds, hematoma, wound infection, or thromboembolism. The clinical relevance of wound drains may be different in association with hip arthroplasties performed through a different surgical approach, those performed with the patient under normotensive general anesthesia, and those performed with cementless fixation.

McGregor AH, Rylands H, Owen A, Dore CJ, Hughes SP. Does preoperative hip rehabilitation advice improve recovery and patient satisfaction? *J Arthroplasty.* 2004;19:464-8.

Thirty-five patients who were awaiting total hip arthroplasty were recruited. The mean age was seventy-two years. The patients were randomized into two groups: Group A received routine preoperative work-up and preparation, and Group B received a preoperative hip-education booklet and attended class for two to four weeks prior to surgery. Clinical assessment was performed with use of the WOMAC, the Harris hip score, and a validated disability scale for daily activities. Psychological assessment was performed with use of several validated instruments. The patients in Group B reported higher levels of satisfaction at the time of hospital discharge and at three months after surgery ($p < 0.01$). Moreover, there was less discrepancy between preoperative expectations and postoperative outcome in Group B ($p < 0.05$). There was no difference between the groups with regard to any of the clinical outcome assessments. There was a 20% reduction in the mean length of hospital stay in Group B, which contributed to a 20% reduction of overall cost in that group. Preoperative education and physical conditioning programs should increase the level of patient satisfaction after surgery. It is unlikely that further reductions in the length of hospital stay and in cost can be realized in the United States from these programs alone.

Pitto RP, Hamer H, Heiss-Dunlop W, Kuehle J. Mechanical prophylaxis of deep-vein thrombosis after total hip replacement: a randomized clinical trial. *J Bone Joint Surg Br.* 2004;86:639-42.

This study was designed to compare the effectiveness of low-molecular-weight heparin with that of pneumatic compression foot pumps when used for prophylaxis against deep-vein thrombosis. All surgical procedures were performed with use of the direct lateral approach with the patient under normotensive general anesthesia. An identical rehabilitation protocol was used after surgery. Screening with use of duplex ultrasound scans was performed before surgery and at three, ten, and forty-five days after surgery. There were 100 patients in each group. No pulmonary emboli occurred in either group. The total rate of deep-vein thrombosis was 3% for the foot-pump group, compared with 6% for the low-molecular-weight-heparin group ($p < 0.05$). The low-molecular-heparin group had greater wound drain output ($p < 0.05$), more transfusions ($p < 0.05$), and more thigh swelling ($p < 0.05$). The foot pump was used for an average of 19.4 hours per day (range, fifteen to 21.5 hours per day). One of the major limitations of the study was the fact that the mean length of hospital stay was twelve days. The use of foot pumps as a stand-alone regimen may not be as effective if only applied for three days, which is the typical mean length of hospital stay in the United States.