ELSEVIER
SAUNDERS

Orthop Clin N Am 36 (2005) 177 – 185

ORTHOPEDIC
CLINICS
OF NORTH AMERICA

Patient Selection and Surgical Technique for Surface Arthroplasty of the Hip

Paul E. Beaulé, MD, FRCSC[a,b,*], John Antoniades, MD[b]

[a]*David Geffen School of Medicine at University of California Los Angeles, Los Angeles, CA, USA*
[b]*Joint Replacement Institute at Orthopaedic Hospital, 2400 S. Flower Street, Los Angeles, CA 90007, USA*

In recent years, there has been a resurgence in the interest of metal-on-metal surface arthroplasty of the hip [1] as an alternative to total hip replacement for the young and active adult [2]. Concomitantly, ceramic-on-ceramic bearings and new polyethylenes are being introduced as promising technology to improve the longevity of standard total hip replacements. Although these technologies are being embraced [3,4] by many, the 10-year survivorship of ceramic-on-ceramic total hips is relatively low at 79% to 85% [5,6] and the new polyethylenes have only 2-year data [7].

Similarly, the renewed interest in the clinically proven low wear of the metal-on-metal bearing [8,9] combined with the capacity of inserting a thin-wall cementless acetabular component [10] has fostered the reintroduction of surface arthroplasty of the hip. As in other forms of conservative hip surgery (ie, pelvic osteotomies [11] and surgical dislocation with femoral head-neck recontouring [12,13]), patient selection helps to minimize complications [14] and the need for early reoperation. Currently, there are two applications for hip resurfacing: hemiresurfacing in the early stages of osteonecrosis [15] and full-surface arthroplasty in the presence of advanced arthritis. In this article, current indications and surgical technique for surface arthroplasty for nonosteonecrotic hip pathology are reviewed.

* Corresponding author. David Geffen School of Medicine at University of California Los Angeles, Los Angeles, CA.

E-mail address: pbeaule@laoh.ucla.edu (P.E. Beaulé).

Patient selection and current clinical results

There have been two recent publications on the short-term results of hybrid metal-on-metal surface arthroplasty that show 94% to 99.8% survivorship at 4 years [16,17]. In both series, patients returned to very high activity levels, with a mean patient age for both series of 48 years old. Amstutz and associates [16] identified several variables that put patients at risk for early failure: femoral head cysts, patient height, and previous hip surgery. In contrast, Daniel and associates [17] emphasized metallurgy and manufacturing of the metal-on-metal bearing as the main determinants for a well-functioning surface arthroplasty: hot isostatic pressing and solution annealing of the components were reported to be unfavorable to the wear properties [18]. Recent analysis and review of metal-on-metal bearings tested in hip simulators by Nevelos and associates [19], however, found no influence of the manufacturing process on the wear properties, with the main determinants for optimal wear performance being relatively low radial clearances and a high carbon content.

As with the introduction of cementless designs in total hip replacements [20], metal-on-metal bearings are not the only answer to the success of surface arthroplasty of the hip [21]. Beaulé et al [14] reviewed the short-term results of patients 40 years old and younger who underwent metal-on-metal surface arthroplasty and identified several independent factors that played a role in their premature failures. A Surface Arthroplasty Risk Index (SARI) was developed and based on a 6-point scoring system: femoral head cyst >1 cm = 2 points; weight <82 kg = 2 points; previous hip surgery = 1 point; and University of

0030-5898/05/$ – see front matter © 2005 Elsevier Inc. All rights reserved.
doi:10.1016/j.ocl.2005.01.001

orthopedic.theclinics.com

California (UCLA) activity score >6 = 1 point. A SARI score >3 represented a 12-fold increase risk in early failure or adverse radiologic changes. In addition, when Amstutz and associates [16] reported on the overall experience in the first 400 hybrid metal-on-metal surface arthroplasties, patients with a SARI >3 had a survivorship of 89% at 4 years versus 97% with a score ≤3. The SARI also proved to be relevant in assessing the outcome of the all-cemented McMinn resurfacing implant (Corin, Cirencester, UK) at a mean follow-up of 8.7 years. Hips that had failed or had evidence of radiographic failure on the femoral side had a significantly higher SARI score than the remaining hips (3.9 versus 1.9), with an overall survivorship at 7 years for the femoral and acetabular components of 93% and 80%, respectively [21].

In respect to the underlying diagnosis, initial analyses have not demonstrated any particular group at greater risk of early failure [16]. Structural abnormalities present with certain diagnoses, however, might pose some difficulties in the positioning and fixation of the components. One such example is dysplasia in which the presence of an acetabular deficiency combined with the inability of inserting screws through the acetabular component may make initial implant stability unpredictable. This deformity in combination with a significant leg-length discrepancy or valgus femoral neck could compromise the functional results after hip resurfacing, and in those situations, a stem-type total hip replacement may provide a superior functional outcome [22]. Surgeons must also consider the overall medical condition of the patient with respect to possible metal hypersensitivity, which could cause persistent pain [23], and compromised renal function because metal ions generated from the metal–metal bearing are excreted through the urine and the lack of clearance of these ions could lead to excessive levels in the blood [9,24].

Finally, as discussed earlier and due to the negative effects of the development of a femoral head cyst on femoral fixation, intervention before the formation of a cyst within the femoral head should be considered for surface arthroplasty of the hip (Fig. 1). This view is obviously contrary to the conventional wisdom of delaying a prosthetic solution for as long as possible; however, the advantages of a pain-free range of motion and maintaining normal activities without the need for anti-inflammatory medication

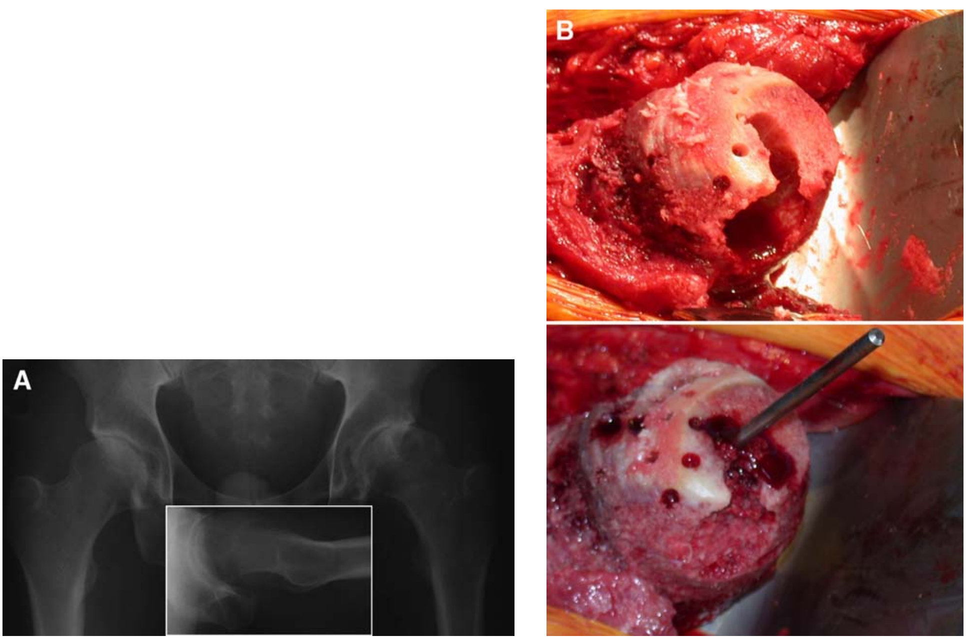

Fig. 1. (*A*) Forty-five-year-old man with an arthritic hip associated with a large femoral head cyst seen on anteroposterior radiograph and cross-table lateral radiograph (*inset*). (*B*) Intraoperative photographs after femoral head preparation showing the size of the cyst pre- (*upper panel*) and postgrafting (*lower panel*) with acetabular and femoral head reamings.

achieved with hip resurfacing cannot be ignored. This practice, combined with the known benefits of physical activity on one's overall health [25], may change how we perceive early prosthetic intervention with a conservative implant versus the inevitable decline associated with hip arthritis and side effects associated with chronic anti-inflammatory medication.

Surgical technique

Currently, the posterior approach is the most commonly used for hip resurfacing as presented by several authors within this issue of the *Orthopedic Clinics of North America*. As discussed by Nork and associates elsewhere in this issue, however, the choice of a surgical approach for hip resurfacing must factor in different anatomic considerations than when performing a standard total hip replacement. With preservation of the femoral head and neck, issues such as vascularity and adequate visualization with minimal trauma to tissues and nerves must be considered [10] (see Nork et al, this issue). For example, the choice of a surgical approach compromising femoral head blood supply [10,26] (see Nork et al, this issue) and causing osteonecrosis could lead to femoral loosening [27] or femoral neck fracture [28] if the lesion is sufficiently large. In addition, because of its conservative nature and goal to closely reproduce the normal anatomy of the proximal femur, positioning of the implants in hip resurfacing may have a greater impact on implant survivorship and patient function than with standard hip replacement.

In the 1982 *Orthopedic Clinics of North America* issue on surface arthroplasty, Hedley [26] emphasized the importance of maintaining femoral head vascularity when considering intervention in early stages of arthritis, whereas in the more advanced stages, an intramedullary source would be sufficient [29]. The discussion at that time was not so much on what surgical approach to use because most surgeons were using a pure anterior [30] or extracapsular trochanteric osteotomy [31], but whether one could safely dislocate the native hip joint without causing osteonecrosis. Subsequent retrieval analysis articles of failed surface arthroplasty failed to identify any major osteonecrotic segments [32–34]; however, the massive granulomatous reaction from the polyethylene wear debris combined with bone resorption secondary to implant micromotion did not leave much of the bone intact at the implant interface. More important, most surgeons at that time were performing hip resurfacing through approaches that left the obturator externus tendon intact, protecting the branch of the medial circumflex artery [35]. In addition, there is recent evidence that the blood supply pattern in advanced arthritis is not significantly different than in the nonarthritic state [36]. Recent work on arthritic femoral heads presented at the annual Orthopaedic Research Society meeting in Washington, DC demonstrated using laser doppler flowmetry that damage to the extraosseous blood supply to the femoral head (retinacular vessels) can cause a significant decrease (greater than 50%) in blood flow [36]. Further follow-up and research is required before the role of femoral head vascularity on the clinical outcome of hip resurfacing can be fully assessed; however, the choice of a surgical approach that minimizes the risk of damaging the blood supply to the femoral head needs to be strongly considered. This choice may become even more crucial as surgeons consider cementless fixation on the femoral side and earlier intervention in the arthritic process to avoid the development of femoral head cysts.

In sharp contrast to stem-type total hip replacements, femoral component positioning in the coronal and the sagittal/axial planes has a narrower margin of error and is dependent on the surgical technique [37] and influenced by the underlying pathology/deformity that led to the degenerative changes. In the coronal plane, varus placement should be avoided, with a relative valgus of 5° to 10° degrees minimizing the tensile stresses at the superior bone–prosthesis junction [29,37]. For example, placement of the femoral component at 130° compared with 140° would increase the tensile stresses by 31%. In the sagittal/axial plane, restoring or maintaining head-neck offset is different than with a stem-type total hip replacement. Although impingement after total hip replacement has long been recognized to limit range of motion [38] and, in extreme cases, lead to hip instability [39], the risk after surface arthroplasty may be greater because the femoral head-neck unit is preserved. This is particularly true in hips in which the arthritis was secondary to femoro acetabular impingement [40]. This common cause of hip arthritis is felt to be secondary to a lack of femoral head-neck offset in the anterolateral area of the femoral head-neck junction [41–43]. If this pathology is left unrecognized after surface arthroplasty of the hip, patients could still experience impingement between the rim of the acetabulum or with the acetabular component itself [44] or have a restricted range of motion. Thus, at the time of resurfacing arthroplasty, removal of prominent anterior neck osteophytes or anterior translation of the femoral component should be considered to avoid this phenomenon [10].

To illustrate some of these different technical points, a series of four case illustrations is presented. The authors do not discuss the detailed surgical technique, which has been described elsewhere [1,10]. The implant used by the senior author (P.E.B.) is the Conserve Plus design (Wright Medical Technology, Memphis, Tennessee) manufactured from high carbon cast cobalt-chromium-molybdenum conforming to ASTM F75 standards. It is available in sizes from 36 to 54 mm in 2-mm increments. Two shell sizes are available in terms of wall thickness: 3.5 mm (thin shell) and 5.0 mm (thick shell). The femoral component has a short stem to ensure accurate alignment, with a uniform cement mantle around the resurfaced femoral head. To provide some cement mantle for the short stem, the authors recommend over-reaming by 2 mm with the stem reamer. No data are yet available on how cementing the short stem may improve long-term survivorship, but the authors have not seen any negative effects [45]. Finally, it is unclear what the optimal cement mantle is on the femoral side because recommendations and designs vary between manufacturers. For example, the Conserve Plus and the DuROM (Zimmer, Warsaw, Indiana) tend to have a thicker mantle than the Birmingham Hip Resurfacing (Smith Nephew, Memphis, Tennessee) and the Cormet 2000 (Corin, Cirencester, UK) designs. In the latter two designs, this thinner mantle results in deeper penetration of the cement into the femoral head.

In terms of surgical approach, the senior author (P.E.B.) adopted the digastric approach with trochanteric slide osteotomy [10], which defers slightly from Ganz et al's description [12] in terms of the exposure of the acetabulum during its preparation: the leg is kept in slight flexion with the knee in extension. Because this approach is done through tissue that allows effective apposition during the healing phase and the only fascia that is cut and repaired in tension

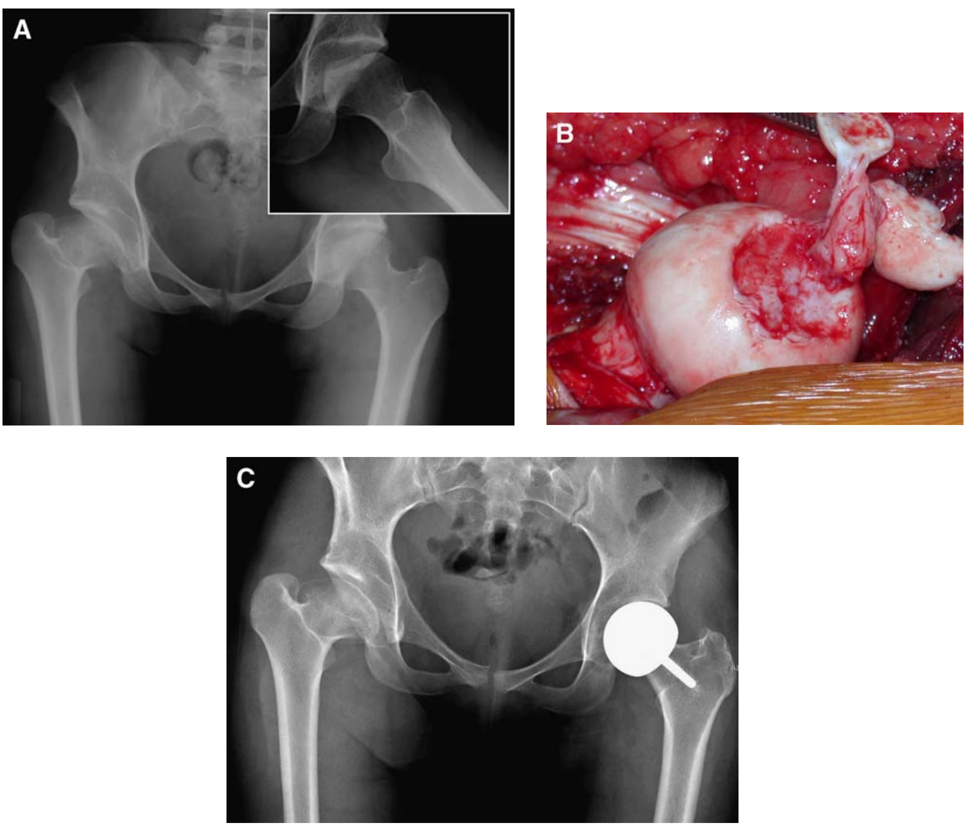

Fig. 2. (*A*) Anteroposterior radiograph and frog lateral radiograph (*inset*) showing the large osteochonral defect of the weight-bearing area of the femoral head. (*B*) Intraoperative photograph showing the femoral head before preparation. (*C*) Anteroposterior radiograph 18 months posthemiresurfacing arthroplasty.

is that between the gluteus maximus and the tensor fasciae lata, it causes no damage intentional or otherwise, to muscles. Thus, not only is this approach less invasive from an implant/bone resection standpoint but it also minimizes soft tissue trauma and facilitates a return to normal function. The trochanteric fragment is usually fixed with two to three 3.5-mm screws, with 50% weight bearing for 4 to 6 weeks, at which time physical therapy is initiated.

Case illustrations

Sequelae of Legg-Calvé-Perthes disease

A 20-year-old woman presented with a history of Legg-Calvé-Perthes disease involving both hips at the age of 9 years. She underwent a pelvic osteotomy on the right hip at the age of 12 years with no treatment on the left hip. She presented with a 1-year history of increasing left hip pain with no associated trauma. This pain was also associated with a clicking and catching in her hip. On physical examination, she had an antalgic gait with some restriction in range of motion, with a positive impingement test. Plain radiographs revealed a large osteochondral defect with no evidence of arthritis (Fig. 2A). Femoral head allograft reconstruction and hemiresurfacing arthroplasty were discussed. The patient elected to undergo the hemiresurfacing arthroplasty. At the time of surgical intervention, there was a large femoral defect with a loose osteochondral fragment (Fig. 2B). Using suture anchors, the labrum was repaired to re-establish the fluid seal in the hip joint. A super-finished Conserve Plus femoral component was cemented in placed after appropriate sizing (Fig. 2C). The screws were removed at 1 year. At 18 months' follow-up, the patient is functioning well with pain only after long periods of standing or use of high heels.

This case illustrates the use of the Conserve Plus super-finished femoral component as a hemiresurfacing component that can later be converted to full-surface arthroplasty, leaving the femoral component in situ. In terms of surgical technique, alignment of the femoral component within the anatomic neck axis was done to minimize joint reaction forces on the acetabular cartilage, thus a valgus orientation was purposely avoided [37].

Protrusio acetabuli

A 17-year-old boy presented with severe pain in the left hip for 1 year, requiring the use of crutches for ambulation. His range of motion was restricted, with only 70° of flexion and 15° of rotational arc. His right hip was asymptomatic (Fig. 3A). The acetabulum was reconstructed with a modular cementless shell, and the femoral component was cemented. Allomatrix (Wright Medical Technology) with reamings of the femoral head were used to graft the medial wall deficiency. At 1-year post surgery, the patient returned to his normal activities, with both hips being asymptomatic (Fig. 3B).

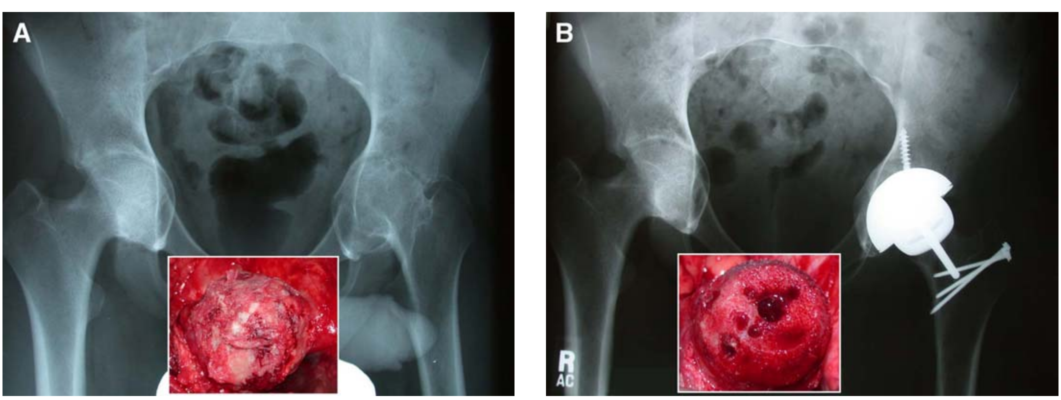

Fig. 3. (*A*) Anteroposterior radiograph showing the protrusio deformity and destruction of the left hip joint. Inset is an intraoperative picture of the femoral head. (*B*) One-year postoperative anteroposterior radiograph showing a well-fixed hybrid metal-on-polyethylene hip resurfacing arthroplasty. Inset photograph shows the femoral head after preparation. The acetabulum was reconstructed with a modular cementless shell (58-mm outside diameter; Trabecular Metal Cup, Zimmer, Warsaw, IN) and a highly cross-linked polyethylene (40-mm inner diameter; Longevity, Zimmer).

To restore the hip center and correct the pincer type of femoroacetabular impingement [40], grafting and supplementary screw fixation of the acetabulum was necessary. In this situation, the use of a modular acetabular component was used, permitting the use of two possible femoral component sizes: 36 mm and 40 mm. The current wear properties and early clinical results of the new highly cross-linked polyethylenes [7,46] make them a reasonable alternative to the metal-on-metal bearing in cases where the acetabulum has sufficient capacity for the acetabular component. On the femoral side, because the 40-mm component was the largest that could be used and to prevent notching of the femoral neck and excessive thinning of the head-neck junction, the authors stopped the reaming down at 42 mm and cemented a 40-mm femoral component. With the Conserve Plus system and despite under reaming, the femoral component can be fully seated but with a thinner cement mantle.

Insufficient head-neck offset

A 40-year-old man presented with a 5-year history of right hip pain that had worsened in the last 8 months. There was no history of childhood hip disorders or significant traumatic events. The patient had been a professional skateboarder and wanted to return to that sport and to snowboarding. His other hip was asymptomatic. On preoperative radiographs, the hip had a classic pistol grip appearance, with an offset ratio on the cross-table lateral of 0.10 (Fig. 4A). This ratio is calculated by dividing the anterior offset by the head diameter [42]. The patient underwent metal-on-metal resurfacing arthroplasty and at 2 years post surgery is back to professional skateboarding and winter sports. On the postoperative cross-table lateral, the offset ratio was improved to 0.22 (Fig. 4B).

Posttraumatic

A 32-year-old man developed avascular necrosis and posttraumatic arthritis after open reduction and internal fixation for an acetabular fracture sustained in a motor vehicle accident 4 years ago. The patient now had constant pain in his hip, significantly restricting his ambulation that was further limited by a leg-length discrepancy of 2 cm and partial peroneal nerve palsy. Radiographs including Judet obliques revealed retained internal fixation on both columns with loss of acetabular bone stock (Fig. 5A, B). After appropriate consultation and discussion of other options such as hip arthrodesis [47], the patient elected to undergo a metal-on-metal surface arthroplasty of the hip. The patient underwent removal of the hardware through an ilioinguinal approach and insertion of the metal–metal surface arthoplasty through the trochanteric slide osteotomy. The leg-length correction was achieved by restoring the hip center with a porous, beaded acetabular component (Conserve Plus), providing a secure initial press-fit without the need for adjunct fixation.

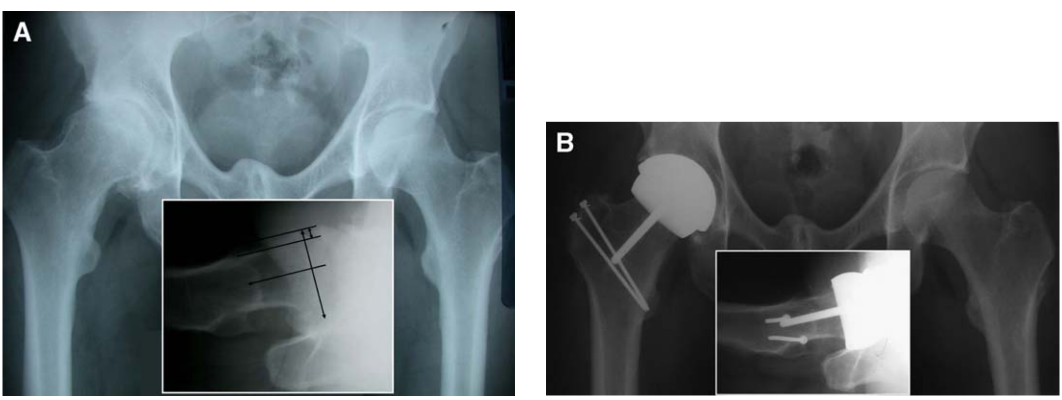

Fig. 4. (*A*) Anteroposterior radiograph showing aspherical femoral head with advanced arthritic changes. Inset demonstrates offset ratio measurement on the cross-table lateral radiograph. (*B*) Postoperative anteroposterior radiograph at 2 years post metal-on-metal hip resurfacing. Inset shows appropriate offset restoration on the cross-table lateral radiograph.

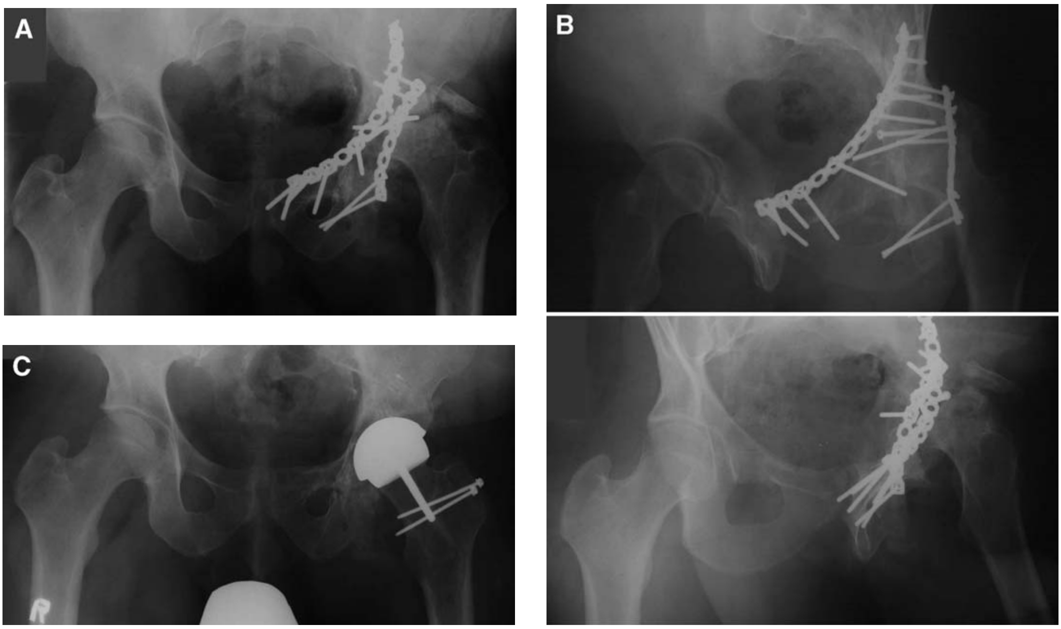

Fig. 5. (*A*) Anteroposterior radiogaph demonstrating the femoral head deformity and leg-length discrepancy. (*B*) The Judet 45° obliques demonstrate that the roof of the acetabulum is deficient but the anterior and posterior columns are relatively intact. (*C*) Anteroposterior radiograph post hybrid resurfacing arthroplasty.

At 2 years, the patient is doing well with minimal pain. Radiographs reveal a correction of the initial leg-length discrepancy and no evidence of component loosening (Fig. 5C).

Summary

The last symposium that was published on surface arthroplasty of the hip [48] concluded that surface arthroplasty should not be considered a standard arthroplasty, should be performed only by surgeons with considerable experience in hip reconstruction, and should be considered in the stage of evaluation. These conclusions are still true today. For surface arthroplasty of the hip to be considered a viable alternative to total hip replacement, certain goals must be met: achieve survivorship superior to 90% at 5 to 10 years, prove itself as a reproducible technique, and confirm its ease of conversion to total hip replacement. Finally, preserving femoral head vascularity by careful surgical technique needs to be considered to optimize the long-term outcome and permit intervention earlier in the arthritic process.

References

[1] Beaule PE, Amstutz HC. Surface arthroplasty of the hip revisited: current indications and surgical technique. In: Sinha RJ, editor. Hip replacement: current trends and controversies. New York: Marcel Dekker; 2002. p. 261–97.

[2] Sochart DH. Relationship of acetabular wear to osteolysis and loosening in total hip arthroplasty. Clin Orthop 1999;363:135–50.

[3] D'Antonio JA, Capello WN, Manley M, et al. New experience with alumina-on-alumina ceramic bearings for total hip arthroplasty. J Arthroplasty 2002;17(4): 390–7.

[4] Garino JP. Modern ceramic-on-ceramic total hip systems in the United States. Clin Orthop 2000;379: 41–7.

[5] Hamadouche M, Boutin P, Daussange J, et al. Alumina-on-alumina total hip arthroplasty: a minimum 18.5-year follow-up study. J Bone Joint Surg [Am] 2002;84(1):69–77.

[6] Bizot P, Banallec L, Sedel L, et al. Alumina-on-alumina total hip prostheses in patients 40 years of age or younger. Clin Orthop 2000;379:68–76.

[7] Heisel C, Silva M, dela Rosa M, et al. Short-term in vivo wear of cross-linked polyethylenes. J Bone Joint Surg [Am] 2004;86(4):748–51.

[8] Sieber H-P, Rieker CB, Kottig P. Analysis of 118 second-generation metal-on-metal retrieved hip implants. J Bone Joint Surg [Br] 1999;81(1):46–50.
[9] Brodner W, Bitzan P, Meisinger V, et al. Serum cobalt levels after metal-on-metal total hip arthroplasty. J Bone Joint Surg [Am] 2003;85(11):2168–73.
[10] Beaulé PE. A soft tissue sparing approach to surface arthroplasty of the hip. Oper Tech Ortho 2004;14(4):16–8.
[11] Trousdale RT, Ekkernkamp A, Ganz R, et al. Periacetabular and intertrochanteric osteotomy for the treatment of osteoarthrosis in dysplastic hips. J Bone Joint Surg [Am] 1995;77(1):73–85.
[12] Ganz R, Gill TJ, Gautier E, et al. Surgical dislocation of the adult hip. A new technique with full access to the femoral head and acetabulum without the risk of avascular necrosis. J Bone Joint Surg [Br] 2001;83(8):1119–24.
[13] Beck M, Leunig M, Parvizi J, et al. Anterior femoroacetabular impingement. Part II. Midterm results of surgical treatment. Clin Orthop 2004;418:67–73.
[14] Beaulé PE, Dorey FJ, LeDuff MJ, et al. Risk factors affecting outcome of metal on metal surface arthroplasty of the hip. Clin Orthop 2004;418:87–93.
[15] Beaulé PE, Amstutz HC. Treatment of Ficat stage III and IV osteonecrosis of the hip. J Am Acad Orthop Surg 2004;12(2):96–105.
[16] Amstutz HC, Beaulé PE, Dorey FJ, et al. Metal-on-metal hybrid surface arthroplasty: two to six year follow-up. J Bone Joint Surg [Am] 2004;86(1):28–39.
[17] Daniel J, Pynsent PB, McMinn DJW. Metal-on-metal resurfacing of the hip in patients under the age of 55 years with osteoarthritis. J Bone Joint Surg [Br] 2004;86(2):177–84.
[18] McMinn DJW. Development of metal/metal hip resurfacing. Hip Int 2003;13(1 Suppl 2):S41–53.
[19] Nevelos J, Shelton JC, Fisher J. Metallurgical considerations in the wear of metal-on-metal hip bearings. Hip Int 2004;14(1):1–10.
[20] Jones LC, Hungerford DS. Cement disease. Clin Orthop 1987;225:192–206.
[21] Beaulé PE, LeDuff M, Campbell P, et al. Metal-on-metal surface arthroplasty with a cemented femoral component: a 7–10 year followup study. J Arthroplasty 2004;19(8 Suppl 3):17–22.
[22] Silva M, Lee KH, Heisel C., et al. The biomechanical results of total hip resurfacing arthroplasty. J Bone Joint Surg [Am] 2004;86(1):40–1.
[23] Willert H-G, Buchhorn GH, Fayyazi A, et al. Metal-on-metal bearings and hypersensitivity in patients with artifical hip joints. A clinical and histomorphological study. J Bone Joint Surg [Am] 2005;87(1):28–36.
[24] Jacobs J, Skipor A, Doorn P, et al. Cobalt and chromium concentrations in patients with metal on metal total hip replacements. Clin Orthop 1996;329S:S256–63.
[25] Paffenbarger RS, Hyde RT, Wing AL, et al. Physical activity, all-cause mortality, and longevity of college alumni. N Engl J Med 1986;314(10):605–13.
[26] Hedley AK. Technical considerations with surface replacement. Orthop Clin N [Am] 1982;13(4):747–60.
[27] Bell RS, Schatzker J, Fornasier VL, et al. A study of implant failure in the Wagner resurfacing arthroplasty. J Bone Joint Surg [Am] 1985;67:1165–75.
[28] Amstutz HC, Le Duff MJ, Campbell PA. Fracture of the neck of the femur after surface arthroplasty of the hip. J Bone Joint Surg [Am] 2004;86(9):1874–7.
[29] Freeman MAR. Some anatomical and mechanical considerations relevant to the surface replacement of the femoral head. Clin Orthop 1978;134:19–24.
[30] Wagner H. Surface replacement arthroplasty of the hip. Clin Orthop 1978;134:102–30.
[31] Amstutz HC, Graff-Radford A, Mai L, et al. Surface replacement of the hip with the THARIES system. J Bone Joint Surg [Am] 1981;63(7):1069–77.
[32] Howie DW, Cornish BL, Vernon-Roberts B. The viability of the femoral head after resurfacing hip arthroplasty in humans. Clin Orthop 1993;291:171–84.
[33] Campbell PA, Mirra J, Amstutz HC. Viability of femoral head treated with resurfacing arthroplasty. J Arthroplasty 2000;15(1):120–2.
[34] Freeman MA, Bradley GW. ICLH surface replacement of the hip. An analysis of the first 10 years. J Bone Joint Surg [Br] 1983;65(4):405–11.
[35] Gautier E, Ganz K, Krugel N, et al. Anatomy of the medial circumflex artery and its surgical implications. J Bone Joint Surg [Br] 2000;82(5):679–83.
[36] Beaule PE, Campbell PA, Hoke R. Femoral head vascularity and notching of the femoral neck during surface arthroplasty of the hip. Washington, DC: Orthopaedic Research Society; 2005.
[37] Beaule PE, Lee J, LeDuff M, et al. Orientation of femoral component in surface arthroplasty of the hip: a biomechanical and clinical analysis. J Bone Joint Surg [Am] 2004;86(9):2015–21.
[38] Amstutz HC, Markolf KL. Design features in total hip replacement. In: Harris WH, editor. Proceedings of the Hip Society. St. Louis (MO): The Hip Society; 1974. p. 111–24.
[39] Bartz RL, Noble PC, Kadakia NR, et al. The effect of femoral component head size on posterior dislocation of the artificial hip joint. J Bone Joint Surg [Am] 2000;82(9):1300–7.
[40] Ganz R, Parvizi J, Leunig M, et al. Femoroacetabular Impingement: a cause for osteoarthritis of the hip. Clin Orthop 2003;417:112–20.
[41] Ito K, Minka-II MA, Leunig S, et al. Femoroacetabular impingement and the cam-effect. J Bone Joint Surg [Br] 2001;83(2):171–6.
[42] Eijer H, Leunig M, Mahomed N, et al. Cross-table lateral radiographs for screening of anterior femoral head-neck offset in patients with femoro-acetabular impingement. Hip Int 2001;11(1):37–41.
[43] Beaulé PE, Zaragoza EJ, Copelan N. 3-Dimensional computer tomography in the assessment of femoroacetabular impingement. San Francisco (CA): Orthopaedic Research Society; 2004.
[44] Wiadrowsk TP, McGee M, Cornish BL, et al. Periph-

eral wear of Wagner resurfacing hip arthroplasty acetabular components. J Arthroplasty 1991;6(2):103–7.
[45] Amstutz HC, Beaulé PE, LeDuff MJ. Hybrid metal-on-metal surface arthroplasty of the hip. Oper Tech Ortho 2001;11(4):253–62.
[46] Digas G, Karrholm J, Thanner J, et al. Highly cross-linked polyethylene in total hip arthroplasty: randomized evaluation of penetration rate in cemented and uncemented sockets using radiostereometric analysis. Clin Orthop 2004;429:6–16.
[47] Beaule PE, Matta JM, Mast JW. Hip arthrodesis: current indications and techniques. J Am Acad Orthop Surg 2002;10:249–58.
[48] Steinberg ME. Summary and conclusions: Symposium on Surface Replacement Arthroplasty of the Hip. Orthop Clin N [Am] 1982;13(4):895–902.