Original Article
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Porous Femoral Fixation in Total Hip Arthroplasty with Short Anatomical Stem: Radiographic Evaluation

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Background: Hip prostheses with short anatomical stems were designed for metaphyseal fixation and to spare bone stock. We present a study of a short anatomical femoral stem used in all age groups of patients with Dorr A and B type of femora.

Methods: We reviewed radiographs of 85 hips in 74 patients who had a cementless total hip arthroplasty with a short anatomical 80 mm femoral stem designed to achieve pure metaphyseal fixation. A ream-only technique was used for femoral canal preparation in all patients. At each follow-up, radiological evaluation was performed for stem alignment, proximal metaphyseal fill, subsidence, status of biological fixation of the femoral stem, heterotrophic ossification, radiolucency, osteolysis, and limb length discrepancy of the stem. Acetabular components were evaluated for positioning, acetabular bone coverage, and radiolucent and osteolytic lesions.

Results: The final mean alignment of femoral stem was 2° valgus. The average intramedullary fill by the stem at the proximal level of the lesser trochanter was 93% in the coronal plane and 88% in the sagittal plane. No components were considered to be undersized. Thirteen hips (15.2%) presented radiolucent lines (10 hips < 1 mm in width and 3 hips [3.5%] 2 mm in width) and 100% of them were not progressive with respect to the last follow-up radiograph. All of the stems had excellent fixation by demonstrating bone ingrowth at the latest follow-up. At the last follow-up, heterotopic ossification was noted in 5 hips. The mean preoperative limb length discrepancy was 9.3 mm and the mean postoperative discrepancy was 3.8 mm. The mean acetabular component angle of the 85 components was 41.2° with a mean anteversion of 22.1°. At the last follow-up, there were no revisions of the femoral component. One patient, 25 months after the index operation, required an acetabular component revision because of recurrent hip dislocation. There were no radiological signs of loosening in any of the short-stem prostheses at the last examination.

Conclusions: The short, metaphyseal-fitting anatomic cementless femoral stem provided stable fixation without relying on diaphyseal fixation.

Keywords: *Arthroplasty, Replacement, Hip*

Obtaining rigid initial fixation, reestablishing normal hip joint biomechanics, and maintaining host bone constitute the main goals of total hip arthroplasty. Aseptic loosening and loss of bone stock have been reported as two of the most frequent long-term complications of cemented total hip arthroplasty.[1)]

Biological fixation of the prosthesis without cement was proposed so that these mechanical failures could be prevented, particularly in younger, active patients. The first cementless stems appeared in the late 1970s and early 1980s. Despite good results in the short-term follow-up, mild and long-lasting outcomes were complicated by

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proximal stress shielding, thigh pain, and osteolysis.[2-4)]

Many implant designs and modifications have been made since then, including a circumferential, proximal porous-coating stem, new alloy materials with a lower elastic modulus such as titanium, and improved implant geometry that provides better metaphyseal and diaphyseal fit and fill.[5-8)]

Currently, cementless fixation is a reliable technique that may be accomplished by either distal fixation in the diaphysis or proximal loading in the metaphysis. The benefits of proximal metaphyseal loading are well documented.[9)]

The original Balance femoral component (Biomet, Warsaw, IN, USA) was introduced in 1994. This titanium alloy stem ranges from 140 to 180 mm in length, is a 3-degree tapered design with a circumferential proximal porous-coated plasma spray. The proximal geometry was defined by the best approximation of the normal femoral anatomy based on the analysis of one thousand computed tomography (CT) scans, which had been catalogued after production of custom femoral implants. Excellent results have been reported with the Balance Hip stem (Biomet) in 399 total hip replacements from May 1994 to December 2002. These results were achieved with reliable osteointegration and no subsidence in spite of immediate postoperative full weight bearing.[10)]

Cementless femoral stems conventionally range from 120 to 160 mm in length, depending on the diameter. This length was based on the premise that some form of fixation in the diaphysis would be necessary to provide a stable implant for eventual ingrowth. However, we believe that diaphyseal fixation is unnecessary for this device, and that a shorter stem with a near-anatomic proximal metaphyseal fit and fill can provide initial stability and long-term fixation through porous ingrowth without the risk of subsidence.

The use of a shorter cementless femoral stem may have a number of advantages. Short stems are utilized more easily than standard length stems when minimally invasive surgery is performed through an anterior approach. In addition, a short stem will preserve diaphyseal bone for later surgery, should a revision be required.[11-14)]

The Balance Microplasty Hip Stem (80 mm; Biomet) is a short stem which was created by use of only the upper one third of the original Balance component. This new design, which is collarless and anatomical, relies solely on metaphyseal fixation without entering the diaphysis.

Previous studies reported radiographic results of the short metaphyseal stem used in a younger group of patients with adequate proximal bone quality.[12)] We hypothesize that the short anatomical stem can provide initial stability and long-term porous fixation, achieve excellent clinical results, and still allow immediate full weight bearing irrespective of age group in Dorr A and B femur.

Our aim in this study was to assess the primary fixation stability and osteointegration of the 80 mm short anatomical femoral component implanted using a ream-only technique.

METHODS

Patients

Between July 2005 and December 2008, a total of 100 primary total hip arthroplasties with the insertion of the cementless hip Balance Microplasty Stem (Biomet) were performed in 91 patients at the University of Chicago Bone and Joint Replacement Center at Weiss Memorial Hospital.

Inclusion criteria for this study were patients who had a preoperative diagnosis of osteoarthritis, avascular necrosis, or rheumatoid arthritis. All of these patients had radiologic bone quality A and B according to the classification of Dorr et al.[15)] Fourteen patients were lost to follow-up during a minimum 2-year radiographic follow-up period. The authors were not aware of any radiographic failure among these 14 patients (15 hips). Ten of 15 hips who were lost to follow-up had either relocated or could not return for evaluation but were evaluated by phone interview and reported that their hips were functioning without pain with high level of satisfaction. Therefore, 77 patients (85 hips) met the inclusion criteria for the current prospective radiographic review.

The mean final follow-up period for these patients after the index surgery was 42.8 months (range, 24 to 61 months). There were 46 men (53 hips) and 31 women (32 hips), with an average age at operation of 51.42 years (range, 33 to 79 years). The mean weight at surgery was 84.55 kg (range, 63.9 to 123.2 kg), and the mean height was 172 cm (range, 167 to 184 cm). The mean body mass index was 28.4 kg/m^2. At the time of surgery, 4 patients had a previous contralateral total hip arthroplasty (THA), 5 patients subsequently underwent a contralateral hip arthroplasty, and 3 patients had simultaneous bilateral THA.

Twenty-eight patients were classified as being in Charnley category A (involvement of the ipsilateral hip, no additional limitations); 19 as Charnley category B (involvement of the contralateral hip, no additional limitations); and 30 as Charnley category C (multiple joint diseases or other disease limiting mobility).[16)]

Hip Implant

The femoral component was designed for a metaphyseal press-fit surgical application, presenting a modified 3-degree bi-planar taper geometry with scratch fit through circumferential plasma spray, and a proximal anatomic fit-and-fill. The stem was 80 mm in length, anatomic, with 5° of anteversion, and it had a type 1 taper. It was composed of titanium alloy, and the 80% proximal portion of the stem was circumferentially coated with porous plasma spray (PPS; Biomet) (Fig. 1).

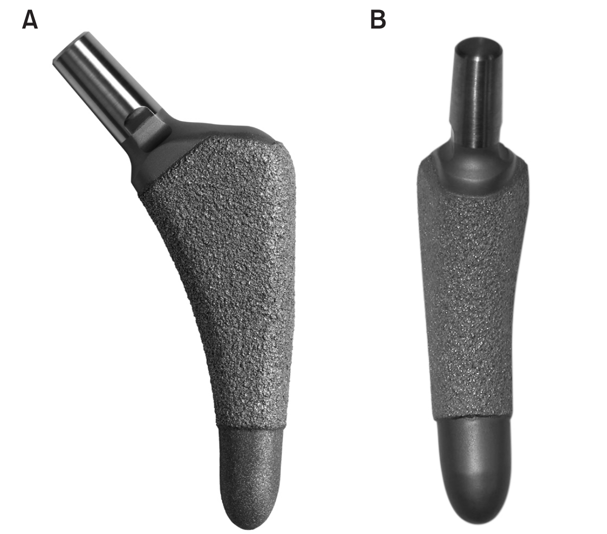

Fig. 1. Sagittal (A) and coronal (B) views of a cementless Balance Microplasty Stem (Biomet) that has a modified 3-degree bi-planar taper geometry. The proximal 80% portion of the stem is circumferentially coated with porous plasma spray.

The acetabulum was resurfaced with a M^2A-Magnum (Biomet) metal-on-metal acetabular component, and a titanium M^2A-Magnum modular head was used in all patients.

Surgical Technique

All of the procedures were performed by the senior author (HF). The surgical team wore body exhaust suits in a clean-air operating room. Perioperative antibiotic prophylaxis with dose-adjusted cefazolin or vancomycin if allergic to penicillin and antithrombotic therapy with warfarin sodium (Coumadin; Bristol-Myers Squibb Co., New York, NY, USA) were given to all patients. A posterolateral approach to the hip without trochanteric osteotomy was used in all cases. The acetabulum was under-reamed by 2 mm, and subsequently, the acetabular component was press-fitted. A ream-only technique was performed in the femoral canal, with removal of all cancellous bone. Short 3-degree conical reamers were designed and utilized for femoral preparation. We normally use starter reamers to find the canal and then 1 mm sequential 3-degree conical reamers until we obtain cortical chatter at the 80 mm point down the femur. The reamer is then medially and laterally tipped toward the calcar, as well as anteriorly and posteriorly, until all metaphyseal cancellous bone is removed. Utilizing power preparation, varus positioning of the femoral component can be prevented after removal of cancellous bone in the greater trochanter. The reamers have a distally extended smooth tip to assist with identification and removal of cancellous bone (Fig. 2). Specific broaches are available and may be used just as trials or as a finishing broach when using a ream-only technique. A

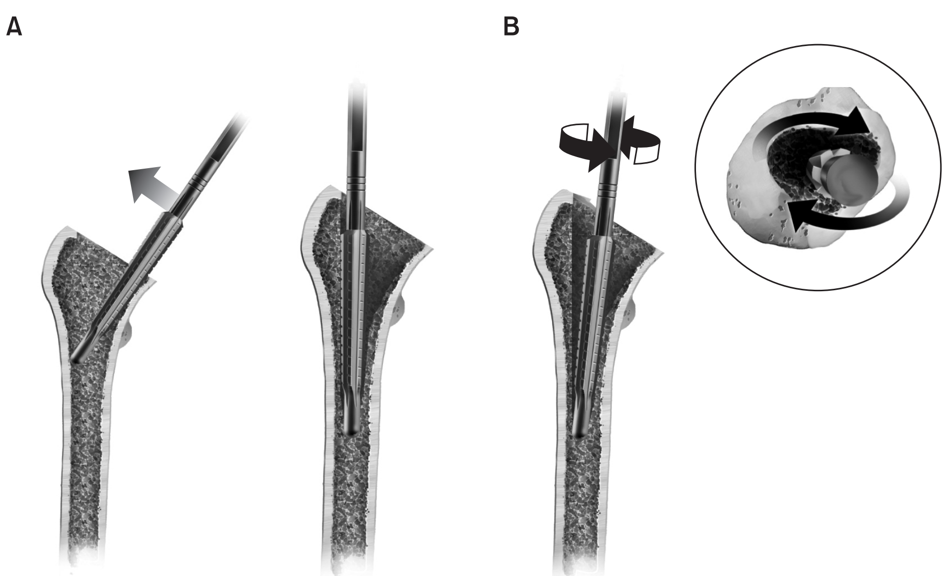

Fig. 2. Schematic of a ream-only technique. (A) Removal of the calcar metaphyseal cancellous bone using a 3-degree conical reamer. (B) Removal of the cancellous bone in the greater trochanter, avoiding varus positioning of the femoral component.

press-fit technique was used to insert the femoral stem.

Rehabilitation

Each patient was encouraged to begin full weight bearing immediately after surgery without crutches or walker if the patient had adequate balance.

Radiologic Evaluation

Anteroposterior radiographs of the pelvis and of both hips, and lateral radiographs of the hip, were made before the surgery, immediately after surgery, at 6 weeks postoperatively, at 6 months, and annually thereafter. All radiographs were done at our institution (Fig. 3).

One observer (CP) who had not been involved in the surgical procedures evaluated all radiographs on 2 separate occasions. The intraobserver agreement between the 2 radiographic evaluations was very good (Kappa, 0.83).

The immediate postoperative radiographs were used as the baseline for comparison with further radiographs. Measurements were corrected for magnification. The goniometer utilized for the measurements had an accuracy of ± 1°, and the digital caliper an accuracy of ± 0.01 mm (Mitutoyo Corp., Kanagawa, Japan).

Femoral component assessment

Limb length discrepancy was assessed on anteroposterior radiographs of the pelvis, noting the relative positions of the lesser trochanters from a line drawn through the most distal aspect of the ischial tuberosities. Stem alignment (valgus, varus, or neutral position) was documented as the angle formed by intersecting of a line drawn through the femoral longitudinal axis and the center line of the stem.[17] Also, the final change in alignment of the stem was recorded. The metaphyseal fill of the stem in the femoral canal was evaluated by measurement of the ratio of the width of the stem to that of the femoral canal at the proximal border of the lesser trochanter. The intramedullary fill was assessed as satisfactory when the relationship of stem–femoral canal was more than 80% on the anteroposterior radiograph and more than 70% in the lateral view. The femoral component was defined as undersized when the filling was below these criteria.[18] Heterotopic ossification was graded by the classification of Brooker et al.[19]

Anteroposterior and lateral radiologic findings around the femoral stem were located and recorded according to the zones described by Gruen et al.[20] Because of the small size of the stem and because the proximal 80% of the surface was coated with PPS, we readjusted and adapted the bounds of the zones. Zones 1 and 2 were divided by a line through 50% of the lateral porous coated area of the stem. Zones 6 and 7 represented the same areas on the medial side. Zones 3, 4, and 5 included, respectively, the lateral smooth portion, the distal smooth portion, and the medial smooth portion of the stem (Fig. 4).

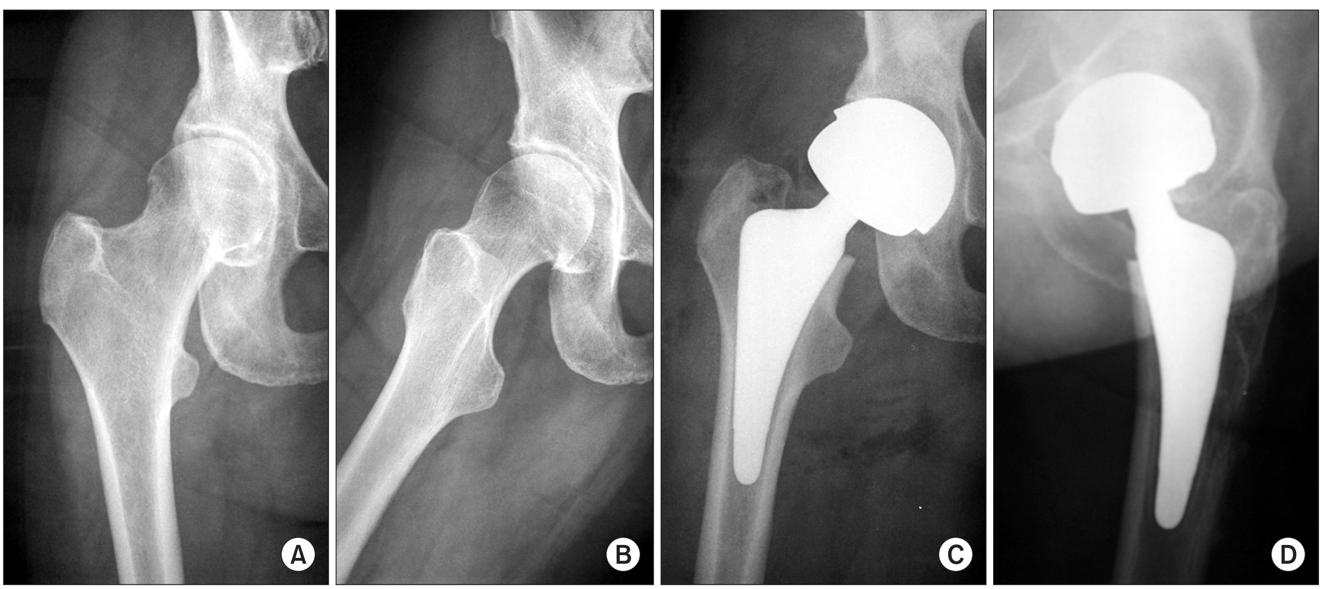

Fig. 3. Preoperative and postoperative radiographs of the right hip of a female who was 65 years old at the time of the right primary total hip replacement. (A and B) Preoperative anteroposterior and lateral radiographs demonstrating osteoarthritis of the hip with partial loss of the joint space and formation of osteophytes. (C and D) Anteroposterior and lateral radiographs at 2 years after total hip replacement with use of a cementless hip Balance Microplasty Stem (Biomet) and a M^2A-Magnum (Biomet) metal-on-metal acetabular component. Note the excellent osseointegration and absence of radiolucent lines at the implant-bone interface.

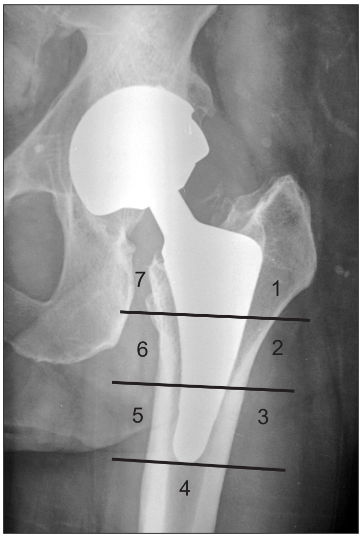

Fig. 4. Gruen's zones. Zones 1 and 2 were divided by a line through 50% of the lateral porous-coated area of the stem. Zones 6 and 7 represented the same areas on the medial side. Zones 3, 4, and 5 included the lateral smooth portion, the distal smooth portion, and the medial smooth portion of the stem, respectively.

Subsidence was determined by measuring distance from the tip of the greater trochanter to the shoulder of the femoral prosthesis (superior lateral aspect of the proximal body of the stem) as well as distance from proximal part of lesser trochanter to shoulder of the prosthesis and the most prominent part of the lesser trochanter to the shoulder of prosthesis.

Radiolucent lines around the femoral stem were measured by use of the zones described by Gruen et al.[20] and Johnston and Crowninshield,[21] and recorded as < 1 mm, between 1 and 2 mm, and > 2 mm in width.

An area of osteolysis was defined as an area of endosteal cavitation (scalloping) greater than 5 mm long or wide adjacent to the femoral or acetabular component, which had not been observed on the postoperative films taken at 6 weeks. Lesions present on the immediate postoperative films were considered gap lesions. The sizes of the osteolytic lesions were measured by multiplying their length by their width, and were classified as small (< 2 cm) or large (> 2 cm). All radiographs were analyzed for osteolytic lesions according to Zicat et al.,[22] and the location was described according to the system proposed by Gruen et al.[20] Also, we utilized the Gruen's classification to localize cancellous condensation (spot welds) adjacent to the porous surface of the stem.

The presence of streaming trabeculations at the coating porous surface of the stem (spot welds) and the complete absence of reactive lines between the endosteal bone surface and the porous portion of the stem were considered major signs for predicting implant fixation by bone ingrowth.

Extensive radiolucent lines around the porous-coated surface of the stem were considered a major sign of failed osteointegration, and the absence of spot welds a minor sign for the absence of osteointegration.[23] Stem subsidence was considered to be any increase in the distance between the radiologic landmarks (superolateral edge of the porous area to the most proximal point of the greater trochanter) and indicative of a major sign of stem instability. In addition, any change in the angle of the stem was considered a sign of instability.[23]

An intramedullary bone pedestal at the tip of the stem was documented as partial or complete, and it was considered an indicator of instability if it was associated with radiolucent lines around the porous-coated area of the femoral component. The status of biological fixation of the femoral stem was evaluated based on the 3 categories described by Engh et al.[23]: (1) stable bone ingrowth; (2) stable fibrous ingrowth; and (3) unstable stem.

Cortical calcar rounding and loss of proximal density were studied by evaluation of sequential postoperative radiographs, and classified as hypertrophy (densification), atrophy (rounding), or indifferent, according to Engh et al.[23] Stress shielding was classified into 4 degrees according to the system of Engh and his associates[24,25] as mild, moderate, severe, or extension to diaphysis.

Acetabular component assessment

The acetabular component angle was assessed by use of the inter-teardrop line as a reference mark, and the plane of the opening of the acetabular component. For evaluation of acetabular component flexion, a line tangential to the face of the cup and a line drawn perpendicular to the horizontal plane were drawn. Acetabular bone coverage was assessed by analysis of anteroposterior and lateral radiographs, and it was estimated as a percentage of acetabular component coverage.

The prevalence, magnitude, and position of radiolucent lines and osteolytic lesions were definite and were categorized according to the 3 zones described by DeLee and Charnley.[26] Periacetabular osteolytic lesions were classified as < 1 cm², > 1 cm², or combined if 2 or more lesions of different sizes coexisted.

Migration was recognized as any change in the acetabular component anteversion angle of > 2°. Migration was also considered to be any vertical change of > 2 mm between the inferior margins of the acetabular component and the ipsilateral radiographic teardrop figure, or any horizontal change of > 2 mm between Kohler's line and the center of the outer shell of the acetabular component.[27)]

An acetabular component with a complete circumferential radiolucent line of < 1 mm in width and without migration was defined to have a stable fibrous fixation. The acetabular component was considered to be probably loose if a complete 2-mm radiolucent line was present on both anteroposterior and lateral radiographic views, and definitively loose if migration was present.

RESULTS

A mean 42.8-month radiographic follow-up assessment after the index procedure, with a minimum of 24 months, was performed for all 77 patients (85 hips).

Femoral Component

In the entire cohort of 85 hips, the final mean alignment of the femoral stem was 2º valgus (range, 5º varus to 4º valgus): 43 stems (50.5 %) were in neutral alignment, 21 (24.7%) in 1° to 3° of valgus, 6 (7%) in 4° to 6° of valgus, 11 (12.9%) in 1° to 3° of varus, and 4 (4.7%) in 4° to 7° of varus. We did not observe any change in alignment between the initial postoperative radiographs and the last follow-up radiographs.

The average of the intramedullary fill by the stem at the proximal level of the lesser trochanter was 93% in the coronal plane, and 88% in the sagittal plane. No components were considered to be undersized. The mean preoperative limb length discrepancy was 9.3 mm (range, –2 to –27 mm), and the postoperative discrepancy was 3.8 mm (range, –4 to 9 mm).

On the latest radiologic follow-up, 13 hips (15.2%) presented radiolucent lines: 10 hips < 1 mm in width, and 3 hip (3.5%) 2 mm in width. All of these radiolucencies were parallel to the stem (nondivergent radiolucencies) and located around the distal 20% nonporous surface of the femoral component (zones 3, 4, and 5). On the lateral radiographs, all of these radiolucent lines were located in Gruen's zones 10, 11, and 12. Eleven of the lucencies (85%) were diagnosed during the first-year radiologic follow-up control, and 100% of them were not progressive with respect to the last follow-up radiograph. No partial or complete bone pedestal was observed in the series.

At 1-year follow-up, 100% of femoral components presented bone ingrowth into the porous areas. According to the criteria of Engh et al.,[23)] 100% of the stems had excellent fixation by demonstrating bone ingrowth at the latest follow-up. Seventy-six hips presented a diffuse pattern of spot welds in zones 1, 2, 6, and 7; meanwhile, 9 hips showed endosteal spot welds limited to specific areas (4 cases in zone 2, 2 cases in zone 1, and 1 case in zone 6).

There were no radiologic signs of migration, subsidence, or loosening in this series. In addition, no proximal or distal osteolysis was present. At the last follow-up, heterotopic ossification was noted in 5 hips: grade I in 4 hips and grade II in 1.

Remodeling changes in the proximal and distal parts of the bone stem interface were assessed. At the last follow-up, analysis of the calcar region showed that 62 hips (72.9%) presented slight rounding of the proximal-medial edge of the cut femoral neck, 14 hips (16.4%) had cortical calcar remodeling associated with loss of medial cortical density, and 9 (10.6%) without any changes. No third or fourth degrees of stress shielding were noted. No evidence of calcar hypertrophy was found.

Acetabular Component

The mean acetabular component angle of the 85 components was 41.2° (range, 34° to 52°) at the time of the most recent follow-up. All components were in anteversion with a mean of 22.1° (range, 10° to 28°). Acetabular host bone coverage was at least 90% in all cases (mean, 96.05%). No gaps, radiolucent lines, or osteolytic lesions were observed around the acetabular component. In addition, there was no radiologic evidence of migration or aseptic loosening of the acetabular component.

At the last follow-up, there were no revisions of the femoral component. One patient, 25 months after the index operation, required an acetabular component revision because of recurrent hip dislocations. During this second procedure, it was observed that the femoral component was well fixed and oriented. After the acetabular revision to a constrained component, no more hip dislocations were observed.

DISCUSSION

Current publications demonstrate that proximally and circumferentially porous-coated implants present almost universally very good to excellent survival at mid-term follow-up.[28)] Complications like wear, osteolysis, or aseptic loosening remain minimal. However, the concern persists to optimize bone conservation through a near-physiologic loading of the femoral neck and metaphyseal region. The Balance Microplasty Hip Stem was created to accomplish this, relying for its stability only on metaphyseal fixation without entering the diaphysis and thus avoiding distal loading and stress shielding.

Primary implant stability based on the press-fitting concept constitutes an essential requirement for achieving osteointegration of the cementless femoral stem, and for obtaining a long-term successful outcome. Osteointegration cannot be assessed with radiologic studies; nevertheless, radiographic changes such as streaming trabeculae, cortical hypertrophy, the absence of subsidence, and radiolucent lines along the ingrowth surface of the implant are concordant with bony stability of the femoral component. Khalily and Whiteside[29] proposed using the 2-year follow-up radiographic changes as predictive for longevity of all cementless porous-coated stem designs.

Our radiographic assessment of bone ingrowth with the short anatomical stem has demonstrated encouraging results. One weakness of this study is that, 14 patients (15 hips) were not available for radiographic evaluation. However, out of these, 10 patients were interviewed and reported doing well and none have been revised. All femoral implants evaluated for radiographic analysis presented streaming trabeculations (spot welds) at the porous-coating surface of the stem, demonstrating that the implant achieved both initial stability and durable bony fixation. No evidence of subsidence, migration, pedestal formation, or radiolucent lines around the porous-coated surface of the stem, despite immediately full weight bearing, were noted. One patient required revision of the acetabular component because of recurrent dislocation. No stems were revised for any reason; neither did we observe any evidence of osteolysis around the femoral or acetabular components in the present series. All of these findings support our hypothesis that diaphyseal fixation appears to be unnecessary for this device, which was designed to provide only metaphyseal loading.

Solely metaphyseal loading has required femoral stem modifications and specific instrumentation. A unique characteristic in this short 80-mm titanium stem is the consistent ventral flare determined by the best approximation of the normal proximal femur based on catalogued CT scan anatomy of normal femora.[10] This design allows a near-anatomic proximal methaphyseal fit and fill, and it provides excellent initial stability and long-term fixation through porous ingrowth. The average coronal and sagittal filling observed in our series were 93% and 88%, respectively. The technique that we use for implanting this device involves a ream-only technique. Shorter 3-degree conical reamers were designed and used for femoral preparation. The implant does not subside, and it becomes extremely stable with a minimal impaction. We found this procedure to be accurate and expeditious, and it eliminates the risk of femur fracture with the broach technique, particularly in patients with Dorr B bone. In addition, preservation of most of the femoral neck during the surgical procedure enhances the torsional stability of the implant, reducing micromotion.

Thorough preoperative planning is an essential requirement for a successful initial stability and long-term porous fixation. Good bone quality of the proximal femur (Dorr bone classification A and B) constitutes essential requirements. Severe coxa valga or coxa vara, particularly associated with a stove pipe or straight proximal femur (Dorr bone classification C), must be considered contraindications for short-stem implants.

We believe that the short anatomical stem with a metal-on-metal bearing or other high demand ceramic or polyethylene bearing is an excellent alternative to hip resurfacing and offers many advantages: it is technically easier to perform, it is more soft tissue sparing, and it is more reliable with use of conventional techniques. Additionally, this device is more easily utilized during minimally invasive surgery, particularly with the anterior approach. This short stem can be easily revised with femoral stems, which invade only the proximal diaphysis, should a later revision be necessary, particularly in younger patients.

Reliable osteointegration despite immediate full weight bearing may be achieved with a short, anatomical femoral component prepared by a ream-only technique. Excellent proximal fit and fill loading the neck and proximal metaphysis in a more physiologic way is the key design feature of such a short stem.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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