

## Technical Factors for Success With Metal Ring Acetabular Reconstruction

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**Abstract:** Sixty-four hips in 62 patients were revised with a Mueller ring (28 hips), Ganz ring (18 hips), and Burch-Schneider cage (18 hips) under the direction of a single surgeon. A polyethylene cup was cemented into the metal support of all hips. Average follow-up was 4.6 years (range, 2.0–6.7 years). Six rings were revised because of aseptic loosening, and 5 others were radiographically loose, for a mechanical failure rate of 11 of 64 (17%). Acetabular metal ring supports failed by migration when defects of  $\geq 60\%$  of the superior weight-bearing bone were filled by only cement or particulate graft. At the time of surgery, the superior rim of the metal support should be against host-bone for 60% of its support, and if not, the use of bulk allograft, rather than particulate graft, is required. Dislocation was the second failure mechanism identified, and this occurred in 15 hips (23%), with reoperation required in 5 hips (8%). A constrained liner should be used in patients with nonunion of the trochanter and preoperative abductor weakness that grades fair/minus or worse as measured by the side-lying abduction test. **Key words:** acetabulum, revision total hip arthroplasty, technique, dislocation, metal rings.

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At this time, the commonest technique for acetabular reconstruction in revision total hip arthroplasty (THA) is the use of a noncemented porous-coated cup with screw fixation. Some hips have severe acetabular osteolysis or migration with loss of bone stock, however. Loss of bone of the superior rim and anterior wall does not prevent the use of a hemispheric cup fixed with screws, but the combination of cavitary and segmental bone loss of the

acetabulum sometimes can produce anatomic deformities that do not permit satisfactory cup fixation. Our experience with the use of solid allograft for these deformed acetabula, particularly with noncemented cups, had been discouraging [1,2]. The alternative use of an acetabular metal ring or antiprotrusion cage was published in September 1992 [3,4], and this information resulted in the decision to use the metal supports in acetabular revision when a hemispheric porous-coated cup could not be made stable. The use of metal rings seemed favorable for protection of bone-graft and the weakened acetabular bone, and they allowed good fixation because the metal could be secured to the pelvis with screws. In the early use of the Burch-Schneider antiprotrusion cage (Sulzer Medica, Baar, Switzerland), we had postoperative weakness of the gluteus medius muscle and a high dislocation rate [5]. We subsequently have experienced a high percentage of loosening of these metal reinforcement rings within 5 years of surgery. The

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purpose of this study was to determine the reasons for revision of hips operated with metal reinforcement supports, including reasons for dislocation, and to describe the technical factors we have learned for improving success.

## Materials and Methods

Between September 1992 and July 1997, 439 revision THAs were performed, and of these, there were 287 revisions of the acetabulum. Metal reinforcement supports were used in 64 of 287 (22.3%) acetabular revisions. These operations were performed under the direction of a single surgeon in all 64 hips in 62 patients. A Mueller ring was used in 27 patients with 28 hips with the center of rotation elevated  $>2$  cm and a cavitory defect that was  $\leq 2.5 \times 2.5$  cm. A Ganz ring was used in 18 patients with 18 hips with the center of rotation elevated  $>2$  cm. A Burch-Schneider cage was used in 18 patients with 18 hips with a deficient posterior wall; a central defect  $>2.5 \times 2.5$  cm; and a *half-moon* shape, which meant absent anterior and medial wall, for a pelvic discontinuity. In 1 patient, a Mueller ring was used in both hips, and in a second patient, the Ganz ring was used in 1 hip and the Burch-Schneider cage was used in the other. In one hip, a Mueller ring was used for a pelvic discontinuity.

There were 44 women and 18 men in this study. The mean age was  $65.6 \pm 12.5$  years (range, 36.0–85.6 years). There were 27 left and 37 right hips. The average follow-up period in this study was  $4.6 \pm 1.4$  years (range, 2.0–6.7 years). Follow-up was  $3.9 \pm 1.4$  years for Mueller rings,  $4.1 \pm 1.2$  years for Ganz rings, and  $5.4 \pm 1.0$  years for Burch-Schneider cages. Preoperative Charnley activity grading was type A in 16 hips, type B in 23 hips, and type C in 25 hips [6]. The average number of previous hip operations was  $2.1 \pm 1.1$  (range, 1–6).

## Technique

The posterior approach was used in all hips. A trochanteric slide was performed in 14 hips and an extended femoral osteotomy in 6 hips to provide better exposure for stem and cement removal. The Dall-Miles cable grip system (Howmedica, Rutherford, NJ) was used to reattach the greater trochanter in these 20 hips as well as in 4 hips with trochanteric nonunion from previous surgery. The acetabular bone was shaped with a reamer, a high-speed bur, or both to allow the ring to be press fit anteriorly and posteriorly between the level of the

anterior inferior iliac spine and posteriorly to the ischium. A bleeding bone bed was prepared for bone-graft or bone-graft substitute. On average, 3 full threaded (range, 2–6) 6.5-mm cancellous screws were used to secure the metal reinforcement by bicortical fixation, or at least with fixation to the inner cortex of the pelvis. Cement was pressurized into the metal reinforcement or bone-graft with the bulb portion of an irrigation syringe (Kendall Company, Mansfield, MA) for approximately 1 minute.

In 24 hips, a polyethylene insert for a metal cup was used as the polyethylene cup in the metal reinforcement support, and the back side of the polyethylene was roughened by a high-speed bur before implantation to improve the cup-cement fixation. In the remaining hips, 3 types of polyethylene cups were used: the Apollo (Sulzer Orthopedics, Austin, TX) polyethylene cup with a 28-mm articulation and a  $10^\circ$  hood in 40 hips; a hooded protrusio acetabular insert (Sulzer Orthopedics, Austin, TX), which permitted the center of rotation to be lateralized by 5 mm compared with a standard insert and had a 28-mm articulation in 12 hips and 32-mm articulation in 4 hips; and the S-ROM (Johnson and Johnson Orthopedics, Braintree, MA) constrained insert with a  $10^\circ$  hood in 8 hips.

## Defects and Bone-Graft

Acetabular defects were classified by the American Academy of Orthopedic Surgeons classification [7]. Type 1 has a segmental deficiency, type 2 has a cavitory deficiency, type 3 has combined deficiencies, type 4 has pelvic discontinuity, and type 5 is an arthrodesis. These defects were classified with preoperative radiographs and were confirmed by intraoperative findings. The type of preoperative acetabular defect and the type of metal reinforcement used are given in Table 1, which shows that cavitory and combined defects were commonest, and the combined defects were treated most often with the Burch-Schneider antiprotrusio cage.

Particulate bone-graft or bone-graft substitute was packed into the acetabulum in 51 hips (78%) before the insertion of a metal reinforcement so that it filled all defects and such that the metal reinforcement ring rested entirely against host-bone, bone-graft, or both. Particulate bone-graft was selected because of our experience with bulk allograft failure [1,2], anticipated improved healing, and successful use by Berry and Muller [3]. Two types of particulate graft were used, with one be-

**Table 1. Comparison of Preoperative Acetabular Defects for Each Type of Metal Reinforcement Supports**

Acetabular Defects	Mueller Ring (n = 28)	Ganz Ring (n = 18)	Burch-Schneider Cage (n = 18)
Segmental defect	2 (7%)	1 (6%)	1 (6%)
Cavitary defect	13 (46%)	11 (61%)	3 (17%)
Combined defect	12 (43%)	6 (33%)	13 (72%)
Pelvic discontinuity	1 (4%)	0	1 (6%)
Arthrodesis	0	0	0

ing cortical cancellous demineralized bone chips (Pacific Coast Tissue Bank, Los Angeles, CA).

### Clinical Assessment

Final clinical assessment by the Harris hip score [8] was done for 55 patients (56 hips) who still were functioning with the metal reinforcements in place. The functional category for each patient before surgery and at final follow-up was determined by 1 of 5 levels based on their walking distance [9]: Unlimited community ambulators have no limitation and participate in sports. Active community ambulators can walk 8 blocks. Limited community ambulators can walk 2 blocks. Household ambulators are limited to their house and yard. Most limited ambulators are in a wheelchair.

The strength of the hip abductors was tested postoperatively using a side-lying abduction test [10]. The side-lying abduction test required strong hip abductors (the gluteus medius and upper head of the gluteus maximus muscles). If the patient could not lift the leg (poor muscle grade) or could not hold the leg in the lifted position against resistance (fair muscle grade), the test was graded positive, meaning that the abductor musculature was weak. If the patient could hold the leg against resistance (good muscle grade) and particularly if this is held strongly against resistance (excellent muscle grade), the side-lying abduction test was negative.

### Rehabilitation

The weight-bearing status of patients postoperatively was 50% and with the use of 2 crutches or a walker for 6 weeks. Twenty-four patients were immobilized postoperatively. Postoperative immobilization was done with a pantaloons cast (around the thigh and waist) for hips with extensive bone-graft or an anterior trochanteric slide or reattachment of nonunion of the trochanter. A hip brace was used

in patients who required only protection against dislocation [10].

### Radiographic Assessment

Radiographic examination included an antero-posterior radiograph of the pelvis, which included the proximal femur, and a 17-inch Lowenstein lateral radiograph of the hip. These radiographs were measured preoperatively, immediately postoperatively, 2 years postoperatively, and at final follow-up or prerevision of the metal reinforcement. The magnification of radiographs was corrected by the known diameter of the metal femoral head. The preoperative, immediate postoperative, and final follow-up radiographs were compared for hip center of rotation and migration of the metal reinforcement support, which was a linear change of >3 mm or rotational change of 8° (Table 2) [11,12]. The center of hip rotation was measured relative to the center of rotation of the normal contralateral hip. In cases with bilateral hip disease, the approximate femoral head center was used as a reference point for measurement [13].

Bone-implant radiolucent lines around the ring and screws were measured in millimeters on the anteroposterior and lateral radiographs according to the zonal analysis of DeLee and Charnley [14]. Progression of a radiolucent line was defined as an increase in the number of zones, an increase in width to  $\geq 2$  mm, or both on sequential radio-

**Table 2. Comparison of Postoperative Radiographic Findings for Each Type of Metal Reinforcement Supports**

Parameter	Mueller Ring	Ganz Ring	Burch-Schneider Cage
Abduction angle of the metal reinforcement support (°)	53.2 ± 15.2	61.9 ± 10.5	70.7 ± 12.6
Abduction angle of the polyethylene cup (°)	43.3 ± 8.5	46.2 ± 12.4	58.0 ± 7.0
Center of hip rotation* (mm)	5.9 ± 12.5	12.6 ± 15.2	16.6 ± 12.5
Change in center of hip rotation† (mm)	(4.3 ± 3.6)	(12.9 ± 9.5)	(5.0 ± 3.5)

\*The value indicates the superior position of the center of hip rotation in the revised hip compared with either the normal contralateral hip or the approximate femoral head center when there was bilateral hip disease.

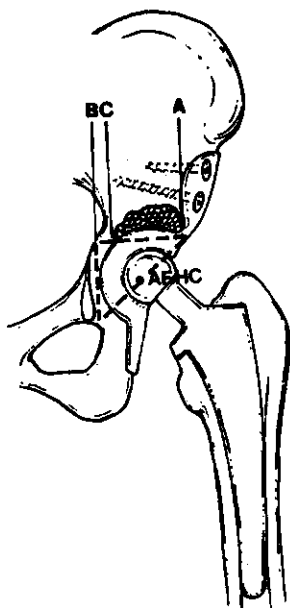
†Indicates improvement of the center of rotation closer to the normal position from the prerevision position.

graphs. These measurements were done using digimatic calipers with a precision of 0.01 mm. Diagnosis of loosening of the cup-ring-bone-graft composite was made by breakage or bending of screws securing the ring or cage; migration; or the development of continuous bone-cement radiolucency  $>2$  mm in width.

A superior subchondral bone defect in the acetabulum was measured horizontally by the percentage of bone loss from the lateral edge of the acetabulum to the inner wall of the pelvis. The width and thickness of bone-graft used to fill the superior acetabular defect was measured from the superior edge of the metal support to the host-bone at the apex of the radius of the ring support that contains the polyethylene cup (Fig. 1). The superior bone defect and the thickness of bone-graft were measured on the immediate postoperative radiograph. Bone-graft was considered to have union if there was bridging trabecular bone between host and graft or remodeling of the graft as observed by development of a smooth border of the graft medially [15,16].

#### Statistical Analysis

Statistical analysis was performed on SPSS (Statistical Software Inc, Chicago, IL). Continuous vari-



**Fig. 1.** The reconstructed acetabulum. The acetabular defect is filled with particulate graft. The distance from the lateral edge of the acetabulum to the inner wall of pelvis (AB) and the horizontal width of the defect (AC) are measured. Percentage of superior bone defect is equal to  $AC/AB \times 100$ .

ables, including Harris hip scores and abduction angles of rings and sockets, were compared using the independent Student *t*-test. Measurements of incidence of radiolucent lines, loosening, and dislocation were compared using the chi-square test. Kaplan-Meier survival analysis [16,17] was performed to calculate the survival rate of the prostheses.

## Results

#### Clinical Assessment

The Harris hip scores of 56 hips without revision of the metal reinforcement at last follow-up (56 of 64 [88%]) averaged  $78.9 \pm 14.2$  (range, 26–98), which improved from the average preoperative score of  $41.4 \pm 13.7$  (range, 19–78;  $P = .000$ ). For the 8 hips in which the metal reinforcement was revised, the last follow-up Harris hip score before revision of the metal reinforcement averaged  $38.1 \pm 19.6$  (range, 15–62). The final average Harris hip score for each type of metal reinforcement used was  $80.1 \pm 17.1$  for hips with Mueller rings,  $78.9 \pm 10.1$  for hips with Ganz rings, and  $76.0 \pm 12.3$  for hips with Burch-Schneider cages. Forty patients (65%) improved their activity level after surgery; however, only one third were capable of walking  $>2$  blocks.

Fourteen hips (22 %) required rerevision surgery of the acetabulum. Eight (12.5%) metal rings were removed—2 because of infection and 6 (10%) because of aseptic loosening. Six hips had revision of the polyethylene cup only because of disassociation of the polyethylene cup from the Burch-Schneider cage in 1 hip and recurrent dislocation in 5 hips. Five other metal supports (1 Mueller ring, 3 Ganz rings, and 1 Burch-Schneider cage) were radiographically loose. Eleven of 64 metal reinforcements were mechanically loose for a mechanical failure rate of 17%.

The overall 6.7-year survivorship using revision of the metal reinforcement as the endpoint was 77.4%; the survivorship for the metal reinforcement rings and the polyethylene cups was 68.0%; and the survivorship for mechanical failure, which includes radiographically loose implants, was 63.5%. The 6-year survivorship for each type of metal reinforcement is shown in Table 3 and shows that revisions are highest for the Burch-Schneider cage, but the mechanical failure for all 3 was not statistically different. There were no loose stems from either those that were not revised or those that were revised.

**Table 3. Six-Year Survivorship for Each Type of Metal Reinforcement Support**

Endpoint for Survivorship	Mueller Ring	Ganz Ring	Burch-Schneider Cage
Revision for any reason	94.1%	88.5%	64.2%
Revision for aseptic loosening	94.1%	94.1%	68.9%
Mechanical failure*	70.3%	63.5%	63.6%

\*Mechanical failure included metal reinforcement supports that were revised for aseptic loosening and those that had radiographic loosening but had not been revised.

### Radiographic Assessment

The Burch-Schneider cage had the most vertical position, and with these metal supports the polyethylene cup was the most vertical (Table 2). This vertical position of the polyethylene cup was skewed higher by the earliest operations that we did [5]. The center of rotation of the femoral head position was improved from prerevision in all hips but remained superior by >1 cm with the Ganz and the Burch-Schneider rings.

The thickness of particulate graft between the superior border of the metal reinforcement and the iliac host-bone and the percentage of subchondral acetabular bone loss in the superior weight-bearing

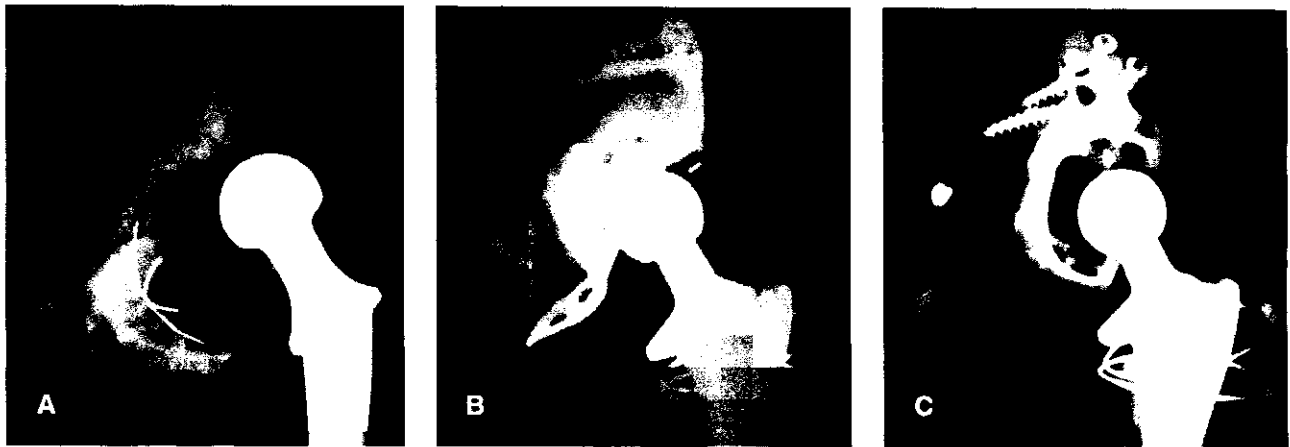
area were related directly to migration of the metal support. All particulate graft in hips with either stable or loose metal support had radiographic evidence of union to the host-bone and remodeling of the graft. Eight of 11 hips (73%) that loosened had at least 5 mm thickness of particulate graft, whereas only 6 of 53 stable metal reinforcements (11%) had  $\geq 5$  mm thickness of bone-graft ( $P = .000$ ), and these 6 hips with stable metal supports had better superior host-bone support (Figs. 2 and 3). Stable rings had an average superior bone defect of  $43.5 \pm 15.4\%$ , whereas in 8 hips that migrated the bone loss was  $72.9 \pm 28.7\%$  (Fig. 1). Overall, in 11 loose metal reinforcements, the average percentage of superior acetabular bone-defect was  $73.0 \pm 24.5\%$ , whereas hips with stable metal reinforcements had an average bone defect of  $37.9 \pm 21.4\%$  ( $P = .001$ ). The types of acetabular defect, the number of screws used for securing the ring, and the location of the hip center of rotation did not influence loosening ( $P = .428, .551, .253$ ).

### Dislocation

Dislocation occurred in 15 hips (23%), which included 6 hips with Mueller rings, 2 with Ganz rings, and 7 with Burch-Schneider cages. Five hips had dislocation as a failure mechanism because it was recurrent and required another revision. In these 5 hips, only the polyethylene cup, modular femoral head, or both were exchanged. In 2 hips,



**Fig. 2.** Anteroposterior radiograph of pelvis. The right hip shows a Burch-Schneider antiprotrusion cage with good position and fixation. The cement column in zone 1 is 1.5 mm thick. There is a radiolucent line between the cement and the bone, but this will not lead to migration because there is intact host-bone supporting the ring. The left hip shows a noncemented cup with contact of the metal to the ilium from the medial to the lateral superior iliac bone showing the most effective host-bone support for either a cup or a ring.



**Fig. 3.** (A) Prerevision anteroposterior pelvic radiograph of a cemented cup rotated 180° in an acetabulum with a combined deficiency. (B) Two-year postrevision radiograph has a radiolucent line in zones 1 and 2 at the graft–host–bone interface. The superior rim of the cage has *no* contact to the host–bone. (C) Five years postoperatively, the Burch-Schneider cage has migrated.

the polyethylene cup position was the primary cause of the dislocation. In 3 hips, a weak gluteus medius (including nonunion of the greater trochanter) was the primary cause [10]. Trochanteric nonunion occurred in 4 hips with an average proximal migration of  $2.3 \pm 1.0$  cm (range, 1–3 cm), and 3 of 4 dislocated. Two of the 4 hips had had a previous trochanteric nonunion, which failed to unite after reattachment.

Dislocation was associated with weak abductor muscle function. Only 1 of 22 hips (5%) with a negative side-lying abduction test dislocated, whereas 14 of 42 hips (33%) with a positive test dislocated ( $P = .001$ ). Dislocation was associated with experience in the use of the metal reinforcement supports. Eleven of the first 32 hips (34%) had dislocation compared with 4 of the second 32 hips (13%;  $P = .04$ ). This improvement was influenced by the use of constrained sockets in 8 of the last 32 hips. None of these 8 patients (with 8 hips) dislocated despite weak abductor muscle function. Postoperative immobilization with a brace or cast did reduce the chance of dislocation from 28% to 17%, but this was not statistically significant ( $P = .32$ ).

### Discussion

There were 2 important findings in this study. First, the amount of bone support in the ilium, which is the superior weight-bearing area of the reinforcement ring, is a crucial factor for stability of

the ring and cup composite and prevention of migration. Second, dislocation is prevalent in complex revision surgery because muscle deterioration commonly is present in hips with multiple operations. The strength of the abductor complex, which is the gluteus medius and upper head of the gluteus maximus muscle, was the most important factor in these hips for the prevention of dislocation.

Surgical technique can reduce loosening and migration of the acetabular metal reinforcement supports. The metal supports are likely to migrate when there is no contact between the superior rim of the cage and the weight-bearing dome area of the host acetabulum (Fig. 1). The chance of loosening increased as the size of defect increased. No migration was found when the defect, on average, was  $\leq 38\%$  of the superior weight-bearing bone (Fig. 2). Migration occurred in every hip (8 of 11 hips) that had bone loss  $>60\%$  of the superior weight-bearing dome. One other hip had 50% to 60% loss so that 9 of 11 hips with loosening had a superior defect  $>50\%$  (Fig. 3). Every loose metal support migrated superiorly into the host–bone defect with or without inferior tilt laterally. This migration suggested that the metal support alone could not withstand the load across the hip joint without a superior bone buttress and that particulate allograft is not strong enough when there is loss of at least 40% of the superior iliac bone of the acetabulum. The necessity to have the ring supported by bone-graft for  $\leq 40\%$  of its superior surface is the same support that is required for bone ingrowth cups [1].

The presence of the superior acetabular weight-bearing bone is necessary for durability of the acetabular reconstruction. To reduce the loosening rate, we suggest that the superior rim of the metal support should be against host-bone for 60% of its support. If the superior bone loss is too large to permit this, which commonly is seen in hips that require a Burch-Schneider cage, the use of structural allograft to reconstruct the defect is required. Other authors confirmed the efficacy of bulk allograft by reporting a 0 to 2.7% loosening rate at 7 to 8 years when structural graft was used with metal support rings to reconstruct defects of >50 % of the superior acetabulum [18–20]. These results are better than the 17% loosening we experienced using particulate graft. Advocates of the Slooff technique have concerns that the use of large metal reinforcement rings can cause stress shielding of the acetabular bone.

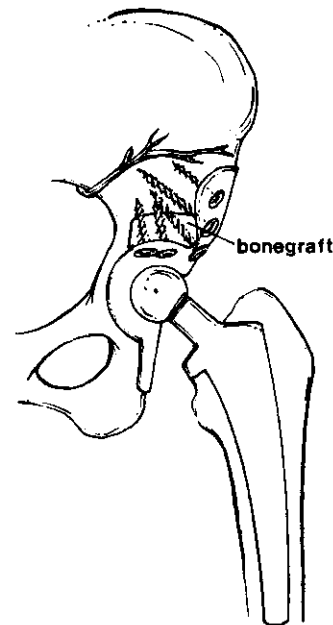
Particulate graft can be used safely only when a defect has <40 % loss of superior host-bone support. This recommendation supports the findings of Zehnter and Ganz [21] and Cabanela [22] that cancellous allografts are too weak to support acetabular ring reconstructions. We had used particulate bone-graft because of our earlier experience with bulk allograft in cementless cups [1,2] the ease of use, and the experience of Berry and Muller [3]. Our experience, combined with that of others, condemns the use of particulate graft as *support* graft with ring reconstruction. It is important to differentiate this ring reconstruction from the acetabular reconstruction advocated by Slooff et al [23], which used packed cancellous bone-graft with wire mesh containment.

The second finding in this study was a high rate of dislocation. The most important reason in these hips was soft tissue imbalance, including a weak gluteus medius and nonunion of the trochanter. The weakness of the abductor muscles, which may be present before the index revision surgery or may be caused by injury to the superior gluteal nerve during the revision, significantly increased the risk of dislocation. In many hips operated for revision of the acetabulum, the superior rim of the acetabulum has been eroded so that the superior edge of the ring support is displaced superiorly. Because of this, the superior flange of the Burch-Schneider cage needs to be secured to the ilium at the same level as is the position of the superior gluteal nerve, which innervates the gluteus medius. The cobra flange of the Burch-Schneider cage is 3.5 cm long, and the superior gluteal nerve innervates the gluteus medius 5 cm above the tip of the greater trochan-

ter [24]. In our patients, because the superior bony acetabular rim had been eroded, the superior pole of the Burch-Schneider cage was located at an average  $6.5 \pm 0.7$  cm (range, 5.0–7.2 cm) above the tip of the greater trochanter on a postoperative radiograph. The gluteus medius muscle had to be retracted for securing the flange onto the bone, and this puts the superior gluteal nerve at risk for injury. The use of structural allograft in hips in which the superior bony acetabular rim has been elevated significantly not only would protect against loosening, but also lower the position of the antiprotrusion cage so that the flange is not placed in a position that threatens the nerve (Fig. 4).

The vertical abduction angle of the cup in the early Burch-Schneider reconstructions was considered a factor in the dislocation rate. The polyethylene cup position within the metal ring support can have a superior portion of the cup uncovered by metal. This uncovered portion of the cup can be supported successfully by cement alone, as was done in many of our hips. No polyethylene cup loosened because of being uncovered superiorly. Proper positioning of the polyethylene cup helps reduce the incidence of dislocation.

Cup position was not as important as was muscle weakness in the occurrence of dislocation. A multiple regression analysis was done, which included



**Fig. 4.** With the use of structural graft to reconstruct the defect, the flange of the cage is lowered below the level of the superior gluteal nerve.

the postoperative side-lying test results, the surgical experience (first 32 hips vs second 32 hips), and the abduction angle of the cup. Only the gluteus medius weakness, as measured by the side-lying test, was associated with dislocation ( $P = .028$ ), and the cup abduction angle was not statistically significant ( $P = .590$ ). Although surgical experience also was not associated significantly with dislocation ( $P = .309$ ), the data were not relevant because constrained cups were used in the second 32 hips. Constrained cups improved the results as evidenced by the finding that 8 hips with gluteus medius weakness and operated with constrained cups did not dislocate. Constrained cups should be used for patients with preoperative nonunion of the trochanter, a preoperative muscle grade of fair/minus or worse, or an intraoperative finding of gluteus medius or maximus atrophy or replacement of muscle fibers with fat. In our experience, we have not had a loose constrained cup or ring-cup composite, but this remains a possibility in the future because of the increased constraint. This use of constraint may be the only predictable solution against dislocation for these patients, however.

Technical decisions at surgery can prolong the durability of acetabular reconstruction with a metal ring support. To reduce the failure by loosening, the superior metal rim should be placed against host-bone for at least 60% of its support. If this amount of bone support is not present, structural graft, rather than particulate graft, should be used to rebuild the superior defect. Particulate allograft can be used with success only in a defect of  $\leq 40\%$  superior bone loss. Particulate allograft can be used as a filler graft in the cavitory defects exclusive of the superior weight-bearing ilium. Dislocation can be reduced by proper placement of the polyethylene cup regardless of the ring position and by the use of a constrained liner in patients with severe preoperative abductor weakness, nonunion of the greater trochanter, and intraoperative evidence of atrophy of the gluteus medius and maximus muscles.

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