Do Large Heads Enhance Stability and Restore Native Anatomy in Primary Total Hip Arthroplasty?

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Abstract

Background Dislocation remains a serious complication in hip arthroplasty. Resurfacing proponents tout anatomic femoral head restoration as an advantage over total hip arthroplasty. However, advances in bearings have expanded prosthetic head options from traditional sizes of 22, 26, 28, and 32 mm to diameters as large as 60 mm. Large heads reportedly enhance stability owing to increased range of motion before impingement and increased jump distance to subluxation. Available larger diameter material

combinations include metal- or ceramic-on-highly cross-linked polyethylene and metal-on-metal, each with distinct advantages and disadvantages.

Questions/purposes We sought to determine (1) if using larger diameter heads has lowered our dislocation rate; and (2) how closely an anatomic metal-on-metal bearing with diameters to 60 mm replicates native femoral head size.

Methods We retrospectively reviewed 2020 primary arthroplasties performed with large heads (≥ 36 mm) in 1748 patients and noted dislocation incidence. In a prospective subset of 89 cases using anatomic heads, native femoral head diameter was measured intraoperatively with calipers by an independent observer and later compared with implanted size.

Results One dislocation has occurred in 2020 hips for an incidence of 0.05%. The prosthetic head averaged 0.7 mm larger than the native head with 68 of 89 (76%) reconstructed to within ± 2 mm of native size.

Conclusions Larger diameter heads have contributed to lower dislocation rates and large-diameter metal-on-metal articulation can provide close anatomic restoration in primary THA.

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Introduction

Dislocation continues to be an unfortunate, frequent complication of primary THA. Reported incidence ranges from less than 1% to 5% with a recent Medicare claims data analysis of 58,521 patients reporting 3.9% dislocation in the first 26 weeks postoperative [31]. Numerous patient factors may contribute to increased dislocation risk: aging, female gender, lower muscular disorders, cognitive dysfunction, dysplasia, previous femoral neck fracture, and rheumatoid arthritis [9, 18, 21, 24, 26, 29, 41]. The correlation between higher surgeon and hospital volume and lower dislocation rates has also been established [20]. Recent advances in implant design allow for use of larger prosthetic heads that more accurately reconstruct native femoral head size and improve head-neck ratio. The desire for larger heads is based on literature that shows a direct relationship between increasing femoral head size and improving implant stability [1, 4, 9–11, 30, 37, 38].

Advances in implant design, manufacturing techniques and tolerances, and metallurgical considerations have allowed development of second-generation metal-on-metal (MoM) implants, which represent an improvement over historical designs. MoM articulations provide reduction in wear and osteolysis and allow a femoral head size that closely resembles the patient's native anatomy [22, 34, 36, 38]. Because the neck of a femoral component is much smaller than the native human femoral neck, matching head size markedly improves head/neck ratio, a benefit in younger patients and those with a high-demand lifestyle. Increased volumetric polyethylene wear has previously limited femoral head size to 32 mm or less. However, the development of highly crosslinked polyethylene and its superior wear characteristics allows use of larger (greater than 32 mm) femoral heads with several reports documenting improved wear characteristics independent of head size [5, 6, 8, 12, 13, 16, 19, 25, 27, 28].

Large femoral heads offer the benefit of increasing the ROM before component-to-component impingement while increasing the displacement necessary before dislocation. It has been recognized that by increasing femoral head component size, a corresponding increase in head-neck ratio occurs, thereby allowing greater ROM [14]. A study conducted on an anatomic full-sized hip model found femoral heads greater than 32 mm virtually eliminate component-to-component impingement [7]. The benefit of

increased head size was seen in a study of 22-mm and 40-mm femoral heads; the displacement required for dislocation increased by approximately 5 mm with 40-mm heads when the acetabular component is in 45° of abduction [10]. A number of studies document increasing femoral head size increases implant stability, thereby reducing postoperative dislocations [1, 3, 9–11, 30]. We previously reported an incidence of 12 dislocations in 1518 primary THAs (0.8%) with femoral heads 32 mm or less through a standard direct lateral approach [24].

With increasing popularity and availability of large femoral heads, we sought (1) to confirm published findings of improved stability with large heads by examining whether 36-mm or larger femoral heads increased hip stability in our practice, both overall and in high-risk patients; and (2) to determine if large head MoM implants accurately replicate the size of the native femoral head in primary THA.

Patients and Methods

A search of our electronic database (Documed, Ann Arbor, MI) identified 1748 patients (2020 hips) who underwent consecutive primary THA between October 2001 and October 2008 in which an unconstrained femoral head 36 mm or larger in diameter was implanted (Table 1). Body mass index averaged 31.1 kg/m² (range, 16.6–68.7 kg/m²). Forty-nine patients (57 THAs) have died at an average of 33.7 months (range, 2–95 months) postoperatively; the status of their hip arthroplasty was known in each patient. The most recent followup data preceding the deaths of those patients were included in this analysis. Followup for all patients was a minimum of 1 month (average, 31 months; range, 1–102 months). Minimum 3-month followup was available for 1699 hips (84%) and minimum 1-year followup for 1469 hip (73%).

The THA bearing surface was MoM in 1635 (81%) hips, metal-on-polyethylene (MoP) in 337 (17%) hips, and ceramic-on-polyethylene (CoP) in 48 (2%) hips. The MoP group consisted of 217 hips with highly crosslinked polyethylene and 120 hips with vitamin E-infused polyethylene. The CoP group consisted of seven hips with highly crosslinked polyethylene and 41 hips with vitamin E-infused polyethylene. All hard-on-hard bearings had heads and liners by the same manufacturer. For MoM, there was a series performed with a 38-mm head articulation and a second series performed with anatomic reconstruction using a head size 6 mm smaller than the acetabular component. In cases with polyethylene, the authors used a minimum thickness of 4.8 mm of polyethylene. Head size was therefore determined by the appropriate size which would accommodate the use of 4.3 mm of polyethylene.

Table 1. Characteristics of present study group with larger heads and previous study of dislocation incidence using smaller heads [24]

Characteristic	Present study	Previous study
Head diameter (mm)	36 and greater	32 and less
Patients (number)	1749	1262
Primary hips (number)	2020	1518
Time period	October 2001 to October 2008	December 1992 to December 1996
Average age (years)	60 (range, 19–91)	63 (range, 41–88)
Gender		
Male	957 (55%)	586 (46%)
Female	791 (45%)	676 (54%)
Preoperative diagnosis		
Osteoarthritis	1608 (80%)	1205 (79%)
Avascular necrosis	185 (9%)	129 (8%)
Posttraumatic arthritis	43 (2%)	84 (6%)
Developmental dysplasia	82 (4%)	36 (2%)
Rheumatoid arthritis	29 (1%)	51 (3%)
Legg-Calvé-Perthes	23 (1%)	13 (1%)
Acute fracture	23 (1%)	0
Slipped capital femoral epiphysis	22 (1%)	0
Psoriatic arthritis	3	0
Osteopetrosis	1	0
Paget's disease	1	0
Surgeon		
AVL	1346 (67%)	808 (53%)
THM	0	710 (47%)
KRB	674 (33%)	0
Approach		
Direct lateral	1815 (90%)	1518 (100%)
Anterior supine intermuscular	204 (10%)	0
Posterior less invasive	1	0
Acetabular component		
RingLoc (Biomet)	362 (18%)	1397 (92%)
Trabecular Metal (Zimmer)	22 (1%)	0
Trident Titanium (Stryker)	5	0
Pinnacle (DePuy)	4	0
ASR (DePuy)	1	0
Arthropor II (DePuy)	0	67 (4%)
ZTT II (DePuy)	0	12 (1%)
DuraLoc (DePuy)	0	12 (1%)
Mallory-Head HexLoc (Biomet)	0	2
Bipolar	0	10 (1%)
M2a-Taper (Biomet)	0	18 (1%)
M2a-38 (Biomet)	749 (37%)	0
Magnum (Biomet)	877 (43%)	0
Femoral component		
Mallory-Head Porous (Biomet)	1425 (71%)	598 (39%)
Mallory-Head Cemented (Biomet)	3	859 (39%)
Mallory-Head Calcar (Biomet)	1	18 (1%)
Mallory-Head Modular Calcar (Biomet)	3	1
TaperLoc (Biomet)	36 (2%)	0

Table 1. continued

Characteristic	Present study	Previous study
TaperLoc Microplasty (Biomet)	534 (26%)	0
TaperLoc Reduced Distal (Biomet)	2	0
Generation 4 (Biomet)	3	0
S-ROM (DePuy)	7	39 (3%)
Link SPII (Waldemar Link)	0	2
M/L Taper Kinectiv Modular (Zimmer)	6	0
DualLock	0	1

The primary indications to proceed with the large-head THA were in individuals who were high demand and would benefit from an alternative bearing and individuals who were considered at a higher risk of dislocation postoperatively. However, because there is no contraindication to using large-head THA in all patients, we have gradually adopted the philosophy of large heads for all patients presenting to our practice who were considered candidates for THA. For the entire period of the study, large heads were used in 73.2% of primary THAs (2020 of 2758). Three hundred seventy-nine (19%) hips were deemed at high risk for dislocation based on age older than 75 years or diagnosis of developmental dysplasia, failure of previous proximal femoral fracture, acute femoral neck fracture, and rheumatoid arthritis [9, 18, 21, 24, 26, 29, 41]. Surgical approach for the majority of cases was direct lateral, used in 1815 of the 2020 (90%) hips, including the less invasive variant introduced in 2003 [2] in 1260 (62%), standard incision in 546 (27%) hips [15], and extended variant in nine (0.4%) hips [15]. The anterior supine intermuscular approach was used in 204 (10%) hips [35] and minimally invasive posterior in one (0.05%) hip.

Patients were allowed full weightbearing in the immediate perioperative period with the assistance of ambulatory aids. The use of the assistive device was discontinued as the patient became pain-free or walked with minimal or no limp. The same postoperative hip precautions were given to each patient to follow for 6 weeks in which they were instructed to sleep on their back, use an elevated toilet seat, use a cushion for all low chairs, not to flex at the waist past 90°, and to avoid excessive adduction such as crossing one leg over the other.

Patients were followed in the immediate postoperative period at approximately 6 weeks and then seen yearly thereafter. Patients were assessed at each followup time using the Harris hip score [17] and beginning in October 2006 using the lower extremity activity scale, a validated, patient-reported activity assessment ranging from 1 (“I am confined to bed all day”) to 18 (“I am up and about at will

in the house and outside. I participate in vigorous physical activity such as competitive level sports daily”) [32].

During 89 THAs performed prospectively using a single anatomic MoM acetabular device, an independent observer (OJF) joined the surgical team, measured the native resected femoral head diameter intraoperatively with a caliper, and recorded his findings. The surgeon and other members of the surgical team were blinded to the measurement and completed the arthroplasty according to a standardized operative protocol that was used throughout this study period. The independent observer then noted and recorded the sizes of implants used.

Chi square analysis was used to compare dislocation rates between the present study and a previously published study from this institution of consecutive primary THA from December 1992 through December 1996. In that study, all cases were performed using smaller heads (≤ 32 mm) and a direct lateral surgical approach (Table 1) [24]. The majority of cases in both studies were performed by one of the authors (AVL) with remaining cases by a second surgeon (previous study: THM, present study: KRB). In our previous study we found 12 dislocations in 1518 primary THAs (0.8%).

Results

One postoperative dislocation occurred out of 2020 THAs for a dislocation rate of 0.05%, a lower ($p < 0.001$) incidence than in our previous study (0.8%) [24]. Considering only the hips performed through a direct lateral approach (less invasive, standard, or extended) ($n = 1815$) in the present study and those using the same approach in the earlier study (1518), there was still a lower ($p < 0.001$) dislocation rate with the larger femoral heads.

Sixty-five (3.2%) hips underwent revision of one or both components. The reasons for revision were from aseptic loosening of the cup in 28 hips, 14 metal-related complications, 11 deep infections, nine periprosthetic fractures, one loose stem with well fixed cup revised, one

Fig. 1 Distribution of femoral head reconstruction accuracy is shown; that is, the difference between the size of the implanted femoral head and the native femoral head.

case with both a loose stem and loose cup revised, and one revision resulting from dislocation secondary to metal complication.

For the 89 THAs in which the resected femoral head measurements were performed intraoperatively, on average, the native femoral head diameter was 49.1 mm (range, 40–58 mm; SD, 4.2 mm) and the implant head diameter was 49.9 mm (range, 40–62 mm; SD, 4.1 mm). Therefore, the prosthetic femoral head averaged 0.7 mm larger than the native resected femoral head (range, –6 mm to 6 mm; SD, 2.4 mm). Sixty-eight of 89 femoral heads (76%) were reconstructed to within ± 2 mm of the native femoral head size (Fig. 1).

Discussion

Postoperative dislocation continues to be a problem that affects many patients both in the immediate postoperative period as well as many years after THA [3, 4, 20, 21, 23, 31, 33, 39–41]. Recent advances have allowed surgeons to implant larger femoral heads, but do these larger femoral heads improve implant stability, and how does the size of the implanted femoral head compare with the patient's native femoral head? A number of studies show increasing the size of the femoral head increases implant stability and reduces the risk of postoperative dislocations [1, 3, 9–11, 30]. To confirm these reports, we asked whether (1) 36-mm or larger femoral heads increase hip stability; and (2) large head MoM implants accurately replicate the size of the native femoral head in primary THA.

There are several limitations to this study. First, most patients were operated on with one of two surgical

approaches, but the large number of patients and the high percentage of patients that have adequate followup more than makes up for this. Second, the followup time was relatively short, averaging 31 months; however, the earlier cases do go back over 8 years when some of the newer MoM designs first became available. Further, some patients were followed only some months (minimum 1–3 months) and some number of these might have had dislocations. Third, patients in the present series underwent a more aggressive postoperative physical therapy and rehabilitation program. In our previous series, patients were generally maintained at bed rest for 1 to 2 days, whereas currently patients are out of bed within 2 hours of the surgical procedure. Therefore, one would expect a higher dislocation rate in the second series versus the first series based on postoperative management. Finally, the femoral head measurements were not a consecutive series of patients, but we believe the large number of direct intraoperative femoral head measurements enhances the validity of this portion of the study.

Several patient factors have been associated with an increased risk of dislocation, including age older than 75 years, acute femoral neck fracture, failure of previous proximal femoral fracture, developmental dysplasia, and rheumatoid arthritis [9, 18, 21, 24, 26, 29, 41]. Three hundred seventy-nine (18.8%) of the hips were deemed high risk for dislocation based on these risk factors and none sustained a dislocation.

MoM is a bearing surface with earlier designs that were prone to failure as a result of poor designs with inadequate engineering and manufacturing processes. Recent designs have corrected these insufficiencies and have made available a bearing surface that has very little wear and subsequent osteolysis [22, 34, 36]. MoM also allows for the use of large-diameter femoral heads, which leads to an increased head-neck ratio as well as a greater jump distance, which increase stability [1, 10, 14]. The advantage of a high head-neck ratio is seen in another study performed on a hip dislocation simulator, in which researchers observed that 38-mm and 44-mm heads virtually eliminated component-to-component impingement [7]. They reported only two instances when component-to-component impingement occurred, in 50° and 47° external rotation and with the leg in 0° extension. In contrast, component-to-component impingement occurred in the 28-mm and the 32-mm heads in 60% and 47% of all cases, respectively.

Our data confirm that large head THA increases implant stability. Technologic advancements in polyethylene as well as MoM prostheses are now allowing surgeons to implant these devices in patients with a number of bearing options. Continued followup of these patients will be necessary to confirm these results.

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References

- Bartz RL, Noble PC, Kadakia NR, Tullos HS. The effect of femoral component head size on posterior dislocation of the artificial hip joint. *J Bone Joint Surg Am.* 2000;82:1300–1307.
- Berend KR, Lombardi AV Jr. Total hip arthroplasty via the less invasive direct lateral abductor splitting approach. *Semin Arthroplasty.* 2004;15:87–93.
- Berry DJ, von Knoch M, Schleck CD, Harmsen WS. The cumulative long-term risk of dislocation after primary Charnley total hip arthroplasty. *J Bone Joint Surg Am.* 2004;86:9–14.
- Berry DJ, von Knoch M, Schleck CD, Harmsen WS. Effect of femoral head diameter and operative approach on risk of dislocation after primary total hip arthroplasty. *J Bone Joint Surg Am.* 2005;87:2456–2463.
- Bragdon CR, Greene ME, Freiberg AA, Harris WH, Malchau H. Radiostereometric analysis comparison of wear of highly cross-linked polyethylene against 36- vs 28-mm femoral heads. *J Arthroplasty.* 2007;22:125–129.
- Bragdon CR, Jasty M, Muratoglu OK, Harris WH. Third-body wear testing of a highly cross-linked acetabular liner: the effect of large femoral head size in the presence of particulate poly(methyl-methacrylate) debris. *J Arthroplasty.* 2005;20:379–385.
- Burroughs BR, Hasstrom B, Golladay GJ, Hoeffel D, Harris WH. Range of motion and stability in total hip arthroplasty with 28-, 32-, 38-, and 44-mm femoral head sizes. *J Arthroplasty.* 2005;20:11–19.
- Burroughs BR, Rubash HE, Harris WH. Femoral head sizes larger than 32 mm against highly cross-linked polyethylene. *Clin Orthop Relat Res.* 2002;405:150–157.
- Conroy JL, Whitehouse SL, Graves SE, Pratt NL, Ryan P, Crawford RW. Risk factors for revision for early dislocation in total hip arthroplasty. *J Arthroplasty.* 2008;23:867–872.
- Crowninshield RD, Maloney WJ, Wentz DH, Humphrey SM, Blanchard CR. Biomechanics of large femoral heads: what they do and don't do. *Clin Orthop Relat Res.* 2004;429:102–107.
- 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;19:41–44.
- Digas G, Kärrholm J, Thanner J, Malchau H, Herberts P. Highly cross-linked polyethylene in cemented THA: randomized study of 61 hips. *Clin Orthop Relat Res.* 2003;417:126–138.
- Digas G, Kärrholm J, Thanner J, Malchau H, Herberts P. Highly cross-linked polyethylene in total hip arthroplasty: randomized evaluation of penetration rate in cemented and uncemented sockets using radiostereometric analysis. *Clin Orthop Relat Res.* 2004;429:6–16.
- D'Lima DD, Urquhart AG, Buehler KO, Walker RH, Colwell CW. The effect of the orientation of the acetabular and femoral components on the range of motion of the hip at different head-neck ratios. *J Bone Joint Surg Am.* 2000;82:315–321.
- Frndak PA, Mallory TH, Lombardi AV. Translateral surgical approach to the hip: the abductor muscle split. *Clin Orthop Relat Res.* 1993;295:135–141.
- Geller JA, Malchau H, Bragdon C, Greene M, Harris WH, Freiberg AA. Large diameter femoral heads on highly cross-linked polyethylene: minimum 3-year results. *Clin Orthop Relat Res.* 2006;447:53–59.
- Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. *J Bone Joint Surg Am.* 1969;51:737–755.
- Hedlundh U, Fredin H. Patient characteristics in dislocations after primary total hip arthroplasty: 60 patients compared with a control group. *Acta Orthop Scand.* 1995;66:225–228.
- Hermida JC, Bergula A, Chen P, Colwell CW, D'Lima DD. Comparison of the wear rates of twenty-eight and thirty-two-millimeter femoral heads on cross-linked polyethylene acetabular cups in a wear simulator. *J Bone Joint Surg Am.* 2003;85:2325–2331.
- Katz JN, Losina E, Barrett J, Phillips CB, Mohamed NN, Lew RA, Guadagnoli E, Harris WH, Poss R, Baron JA. Association between hospital and surgeon procedure volume and outcomes of total hip replacement in the United States Medicare population. *J Bone Joint Surg Am.* 2001;83:1622–1629.
- Khatod M, Barber T, Paxton E, Namba R, Fithian D. An analysis of the risk of hip dislocation with a contemporary total joint registry. *Clin Orthop Relat Res.* 2006;447:19–23.
- Kim RH, Dennis DA, Carothers JT. Metal-on-metal total hip arthroplasty. *J Arthroplasty.* 2008;23(Suppl 1):44–46.
- Kwon MS, Kuskowski M, Mulhall KJ, Macaulay W, Brown TE, Saleh KJ. Does surgical approach affect total hip arthroplasty dislocation rates? *Clin Orthop Relat Res.* 2006;447:34–38.
- Mallory TH, Lombardi AV Jr, Fada RA, Herrington SM, Eberle RW. Dislocation after total hip arthroplasty using the anterolateral abductor split approach. *Clin Orthop Relat Res.* 1999;358:166–172.
- Manning DW, Chiang PP, Martell JM, Galante JO, Harris WH. In vivo comparative wear study of traditional and highly cross-linked polyethylene in total hip arthroplasty. *J Arthroplasty.* 2005;20:880–886.
- Meek RMD, Allan DB, McPhillips G, Kerr L, Howie CR. Epidemiology of dislocation after total hip arthroplasty. *Clin Orthop Relat Res.* 2006;447:9–18.
- Muratoglu OK, Bragdon CR, O'Connor DO, Jasty M, Harris WH. A novel method of cross-linking ultra-high-molecular-weight polyethylene to improve wear, reduce oxidation, and retain mechanical properties. *J Arthroplasty.* 2001;16:149–160.
- Muratoglu OK, Bragdon CR, O'Connor DO, Perinchieff RS, Estok DM, Jasty M, Harris WH. Larger diameter femoral heads used in conjunction with a highly cross-linked ultra-high molecular weight polyethylene: a new concept. *J Arthroplasty.* 2001;16:24–30.
- Paterno SA, Lachiewicz PF, Kelley SS. The influence of patient related factors and the position of the acetabular component on the rate of dislocation after total hip replacement. *J Bone Joint Surg Am.* 1997;79:1202–1210.
- Peters CL, McPherson E, Jackson JD, Erickson JA. Reduction in early dislocation rate with large-diameter femoral heads in primary total hip arthroplasty. *J Arthroplasty.* 2007;22:140–144.
- Phillips CB, Barrett JA, Losina E, Mohamed NN, Lingard EA, Guadagnoli E, Baron JA, Harris WH, Katz JN. Incidence rates of dislocation, pulmonary embolism, and deep infection during the first six months after elective total hip replacement. *J Bone Joint Surg Am.* 2003;85:20–26.
- Saleh KJ, Mulhall KJ, Bershadsky B, Ghomrawi HM, White LE, Buyea CM, Krackow KA. Development and validation of a lower-extremity activity scale. Use for patients treated with revision total knee arthroplasty. *J Bone Joint Surg Am.* 2005;87:1985–1994.
- Sanchez-Sotelo J, Haidukewych GJ, Boberg CJ. Hospital cost of dislocation after primary total hip arthroplasty. *J Bone Joint Surg Am.* 2006;88:290–294.
- Schmalzried TP, Peters PC, Maurer BT, Bragdon CR, Harris WH. Long-duration metal-on-metal total hip arthroplasties with

- low wear of the articulation surfaces. *J Arthroplasty*. 1996;11:322–331.
35. Seng BE, Berend KR, Ajluni AF, Lombardi AV Jr. Anterior-supine minimally invasive total hip arthroplasty: defining the learning curve. *Orthop Clin North Am*. 2009;40:343–350.
36. Sieber HP, Rieker CB, Kottig P. Analysis of 118 second-generation metal-on-metal retrieved hip implants. *J Bone Joint Surg Br*. 1999;81:46–50.
37. Smith TM, Berend KR, Lombardi AV Jr, Emerson RH Jr, Mallory TH. Metal-on metal total hip arthroplasty with large heads may prevent early dislocation. *Clin Orthop Relat Res*. 2005;441:137–142.
38. Stuchin SA. Anatomic diameter femoral heads in total hip arthroplasty: a preliminary report. *J Bone Joint Surg Am*. 2008;90(Suppl 3):52–56.
39. von Knoch M, Berry DJ, Harmsen S, Morrey B. Late dislocation after total hip arthroplasty. *J Bone Joint Surg Am*. 2002;84:1949–1953.
40. Woo RG, Morrey BF. Dislocations after total hip arthroplasty. *J Bone Joint Surg Am*. 1982;64:1295–1306.
41. Woolson ST, Rahimtoola ZO. Risk factors for dislocation during the first 3 months after primary total hip replacement. *J Arthroplasty*. 1999;14:662–668.