The Influence of a Suction Device on Fixation of a Cemented Cup using RSA

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Abstract The quality of technique used at the time of socket cementation is crucial in ensuring a durable long-term result of the implant. We asked whether a new instrument, an aspirator retractor introduced into the wing of the ilium before socket preparation and cementation, would enhance cement fixation as defined by RSA and radiographic examination. We randomized 38 patients into two groups. The surgical technique was identical between the groups with the exception of the use of the aspirator retractor. Patients were followed clinically and with radiostereometry at a minimum of 2 years. We compared gross radiographic appearances, including the depth of penetration of cement and the incidence of postoperative and 2-year radiolucent lines. There was no difference in proximal migration between the two groups. No improvement of fixation was proven from the measured translations and rotations of the socket in the suction group. We found no difference in the number or extent of radiolucent lines or the depth of cement penetration when the iliac suction device was used in conjunction with contemporary cementing techniques. Although the data suggest no short-

term advantage in this small study, we will continue to follow these patients presuming there will be improved outcomes in the longer term and since the device provides an easier method of obtaining adequate fixation, especially if technical difficulties are encountered during the pressurization procedure.

Introduction

The longevity of a cemented socket depends fundamentally on the quality of surgical techniques used at the time of implantation of the device [6, 14, 24]. With good bone preparation of a trabecular bone surface and adequate cement penetration to a depth of 5 mm or more, good mechanical interlock can be achieved, especially if the implanted device is protected from the deleterious effect of blood accumulating at the cement-bone interface [15, 21].

To achieve a strong cement-bone interface in the acetabulum, contemporary surgical technique depends on reamers, drills, powered lavage systems [22], proprietary pressurizers [19], and sometimes a flanged implant [9, 25, 29]. We designed an aspirator retractor in 2000 (Fig. 1) to further assist the surgeon in achieving an ideal implant-bone interface [17].

We asked whether using this device improves cement fixation as defined by radiostereometry (RSA) and gross radiographic appearances at a minimum of 2 years after surgery.

Materials and Methods

The aspirator retractor (Stryker Orthopedics, Mahwah, NJ) is a cannulated retractor designed to be inserted into the

Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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Fig. 1 The Exeter aspirator retractor device is shown with the obturator attached.

wing of the ilium during cemented THA. In addition to acting as a retractor, if suction tubing is applied, it has several other functions. It can be used to suck the lavage fluid away during cleaning of the trabecular bone in the acetabulum. It vents the cavity if hydrogen peroxide-soaked swabs are used and sucks cement into the trabecular bone of the ilium and blood out from the wing of the ilium during cementing of the acetabular component. Thereafter, it helps keep the interface free of blood to promote sound mechanical fixation of the acetabular component [17].

Between June 2002 and April 2003 we asked 52 patients younger than 80 years admitted for THA with a diagnosis of osteoarthritis to enter the trial. If consent was obtained, the patient was randomized by sealed envelopes, opened in the operating room, into one of two groups. The treatment (suction) group had an aspirator retractor introduced into the wing of the ilium at the time of socket preparation. No such device was used in the control group and the operative technique was otherwise identical. We excluded 10 patients who did not consent to participate in the study and another four whose initial postoperative radiographs showed insufficient beads for RSA to be performed. Therefore 38 were entered into the study between June 2002 and April 2003, 20 in the suction group and 18 randomized to the control group. The primary effect variable, used for power analysis, was proximal migration of the cup (Y translation). To estimate a clinically important effect size [5] for power analysis, an assumption of difference in means of 0.5 mm and a standard deviation of 0.5 mm for both groups was made. With a power of 0.8 and a significance level of 0.05, at least 17 patients were needed in each group. These assumptions were confirmed by the results reported by Flivik et al. [11]. Allowing for a loss to followup rate of

15%, an initial aim of 20 patients per group was set. There were equivalent proportions of each gender in each group (39% male). The mean age was 66 years (range, 52–79 years). There were 24 right hips and 14 left which were similarly distributed in the groups. The grades of surgeon are similar between the groups. In the suction group, two surgeries were performed by Consultants, two by Specialist Registrars, and 16 by Fellows. In the control group, three surgeries were performed by Consultants, three by Specialist Registrars, and 12 by Fellows. Two of the 38 patients were lost to followup: one patient in the control group died of a myocardial infarction 1 week after surgery and one patient in the suction group left the United Kingdom to live in France, although clinical scores were available for the latter patient. There was no major difference between the groups regarding any of the clinical preoperative scores (Tables 1, 2).

Other than use of the aspirator retractor (Stryker Orthopedics), all other surgical techniques and protocols were identical between the groups and followed existing practice. Socket preparation included complete removal of the subchondral bone wherever possible. Multiple drill holes were prepared. Between six and nine 1-mm tantalum balls were positioned in the pelvis, at least five spread in the dome and wing of the ilium and at least one each in the pubis and ischium. The same sized tantalum markers also were inserted around the rim of the polyethylene socket and one at the dome of the implant (Fig. 2).

In the suction group, an aspirator retractor was hammered into the wing of the ilium. The inner obturator of the device is sharp and pierces the outer table of the ilium without difficulty. The ideal position is for the tip of the aspirator to be sited just proximal to the most proximal cement drill hole (Fig. 3). The obturator was removed and suction applied during lavage of the bone and during application and pressurization of cement. If copious bleeding was obvious in the sucker tubing, the suction was turned down so that blood loss was kept to a minimum. The device was removed when it became blocked, or when the socket was seated and the viscosity of cement was increasing.

We used a high-pressure lavage system followed by application of hydrogen peroxide swabs to the socket bed before cementing. A small amount of autograft bone was impacted onto the smooth cortex of the true medial wall to enhance fixation immediately before cementation. Simplex antibiotic bone cement (Stryker Orthopedics) was introduced into the cavity by hand at 3 minutes, and high pressure was applied to the cement through an Exeter pressurizer (Stryker Orthopedics) [19] until 6 minutes had elapsed from the start of cement mixing. A flanged socket then was pushed firmly into a prerehearsed position of inclination and anteversion.

Table 1. Median (interquartile range) scores

Score	Time	Suction	Control	p Value
Charnley pain	Preoperative	3 (1)	3 (2)	0.26
(0–6 worst to best)	2 year	6 (1)	6 (1)	1.0
Charnley function	Preoperative	2 (2)	3 (2)	0.83
(0–6 worst to best)	2 year	6 (0)	6 (0)	0.46
Charnley range of motion	Preoperative	4 (2)	4 (2)	0.48
(0–6 worst to best)	2 year	5.5 (1)	6 (0)	0.03
Oxford score	Preoperative	22 (15)	21 (9)	0.41
(0–48 worst to best)	2 year	44 (5)	46 (9)	0.60
Harris hip score - pain	Preoperative	20 (10)	20 (0)	0.50
(0–44 worst to best)	2 year	44 (4)	44 (4)	0.99
Harris hip score - function	Preoperative	25 (7)	26 (9)	0.52
(0–47 worst to best)	2 year	44.5 (8)	42 (8)	0.60

Table 2. Preoperative and 2-year Charnley categories of the two groups

Group	Preoperatively			2 Years		
	A	B	C	A	B	C
Suction	13	4	3	12	6	2
Control	10	7	1	11	5	1

Fig. 2 The radiograph shows distribution of tantalum balls in the pelvis and cup.

The reference RSA examination was done within 6 days after surgery. Patients were allowed to ambulate from the first day after surgery; therefore, all had been weightbearing on the operated limb before the radiographic examination. Additional examinations were performed at 6 weeks and 2 years with a time tolerance of up to 10%.

Conventional radiographs centered on the pubis were obtained to document cement penetration into bone and congruence of the mantle around the implant. Radiographs were scaled using the femoral head to assess magnification.

Fig. 3 The position of the aspirator retractor is shown in the wing of the ilium with the obturator removed.

We noted the appearance and progression of any radiolucent lines between cement and bone of any thickness. On the 2-year films, a radiolucent line will have a radiodense margin on the host side of the interface.

We used a uniplanar RSA technique with the patient carefully positioned in the supine position in the center of the examination table. As much as possible, a standardized patient position was used throughout the series of examinations. One radiographic source was ceiling-mounted and the other was portable. A Type 41 (Tilly Medical Products,

Lund, Sweden) calibration cage was used and analog images were scanned on a digital scanner (Umax Mirage 2, Umax Data Systems, Hsinchu, Taiwan) for analysis using UmRSA version 4 computer software (RSA Biomedical Innovations, Umeå, Sweden). The UmRSA system has been validated in a standardized manner and a phantom was examined to confirm the accuracy of our system. A standard protocol was used for the RSA investigation [30].

The stability of the tantalum markers in a rigid body will influence the accuracy of any measured movement. The stability of the balls traditionally is described in terms of the mean error of rigid body fitting. This is the mean difference between the relative distances of markers in a rigid body in one examination compared with that in another examination. Valstar et al. [30] proposed the upper limit for the mean error of rigid body fitting should be 0.35 mm, which is the figure we used.

The pattern of distribution of the markers also will affect the accuracy of measured movements, and the distribution is assessed using a condition number. This is the mathematical expression of how the markers in an object of interest (the rigid body), related to an arbitrary straight line passing through that rigid body [28]. The larger the value, the more the markers align with the line, that is, the less they lend themselves to the provision of high accuracy. Conversely, the lower the condition number, the better the distribution of the ball in the rigid body. Valstar et al. suggested condition numbers less than 110 are reliable and sufficient for determination of prosthetic migration and recommended against using condition numbers in excess of 130 [30]. To ensure accuracy, we used 115 as the upper limit of acceptability. The films for six patients were not suitable for RSA analysis because the mean error of rigid body fitting was greater than 0.35, the condition number was greater than 115, or both. These patients were recruited at the beginning of the learning curve for RSA examination at our institution.

Translations were described in millimeters, defining segment motion in the three orthogonal directions respecting the right orthogonal coordinate system: X, mediolateral (positive X being medial); Y, distal-proximal (positive Y being superior); and Z, posteroanterior (positive Z being anterior). Rotations of the segment are described around the orthogonal axes; around X axis (flexion-extension), Y axis (external-internal rotation), and Z axis (abduction-adduction). As with the defined convention, positive values are defined for the right extremity so with left hips, the sign will change for rotation around the Y and Z axes. We used absolute figures because the sign is an indication of direction rather than a real number.

The term precision describes the repeatability of an examination and is assessed by double examinations, that is, examination of two sets of radiographs taken of the

same patient after an interval of 10 to 15 minutes has elapsed. Ideally, a double examination should be made for each patient because in every case, there is a unique configuration of markers in the rigid bodies. However, the double dose of radiation required prevented us doing this on actual patients. Instead, repeat examination of a phantom with a distribution of tantalum markers typical for this study was performed on multiple occasions as part of ongoing quality assurance.

The primary outcome measure was migration of the implant measured by RSA. We obtained clinical scores (Harris hip score [13], Charnley modification of the d'Aubigné-Postel score [4], and Oxford hip score [7] on a transformed 0–48 worst to best scale [23]) at each outpatient visit after the 6-week appointment. Patients were seen routinely at 6 weeks, 2 years, 5 years, and then at 5 yearly intervals. Complications and reoperations for any indication were recorded. Radiographically, we (AJT, PH) noted cement penetration into bone, congruence of the cement mantle around the implant, and the appearance and progression of radiolucent lines. Lucent lines were reported in each of the three DeLee and Charnley zones [8] at each time and by the percentage of the interface over which they were observed.

Each RSA variable was not normally distributed. We therefore compared differences with the Mann-Whitney U test). Nonparametric measures of central tendency (median) and variability (interquartile range) also are given where appropriate. Adjustments for multiple testing were made using the Bonferroni [3] correction when applicable. The frequencies of movement direction were analyzed using Fisher's exact test. SPSS software was used (version 11.0; SPSS Inc; Chicago, IL). At 2 years, because there are low expected values in 50% of cells, the table was collapsed; Zones 2 and 3 were combined for this analysis.

Results

We observed no differences between groups in translation or rotation around the axis (Table 3). The frequencies of movement direction (medial or lateral) were similar ($p = 0.682$) for both groups. The amount of movement medially or laterally for each group separately ($p = 0.44$ suction, $p = 0.48$ no suction) also was similar (Table 4).

There was no increase in depth of cement penetration in any DeLee and Charnley zone [8] (Table 5). Postoperative radiolucencies (Table 6) in DeLee and Charnley Zones 1 and 3 were similar ($p = 0.38$). At 2 years combining Zones 2 and 3 radiolucencies were again similar ($p = 1.0$) although there was a trend for progression of radiolucent lines in the control group. Typical postoperative radiographic appearances are shown in Fig. 4.

Table 3. Median (interquartile range) translation (mm) and rotation (degrees)

Direction	Suction	Control	p Value
X-translation	0.15 (0.29)	0.23 (0.21)	0.16
Y-translation	0.17 (0.19)	0.14 (0.13)	0.46
Z-translation	0.23 (0.26)	0.12 (0.19)	0.25
X-rotation	0.18 (0.36)	0.39 (0.45)	0.19
Y-rotation	0.31 (0.44)	0.33 (0.67)	0.29
Z-rotation	0.23 (0.29)	0.23 (0.37)	0.65

Table 4. Mean (95% confidence interval) medial and lateral movement (mm)

Group	Medial	Lateral
Suction	0.13 (−0.11 to 0.37)	0.20 (0.10 to 0.30)
Number	5	11
Control	0.46 (−0.46 to 1.38)	0.23 (0.16 to 0.30)
Number	3	12

Table 5. Mean depth (mm) (standard deviation) of cement penetration by DeLee and Charnley zone

Group	Zone 1	Zone 2	Zone 3
Suction	28.1 (7.2)	11.4 (5.6)	7.4 (5.0)
Control	26.3 (7.2)	16.3 (5.1)	7.1 (2.4)
p Value	0.48	0.02	0.82

At 2 years we observed no differences between the two groups in clinical outcome (Table 1). The groups remained comparable in Charnley designation (Table 2).

Discussion

The aspirator retractor device can be inserted into the wing of the ilium at the time of socket preparation and cementation. The device is used to: (1) increase cement intrusion into the wing of the ilium; and (2) remove blood from the cement-bone interface as it polymerizes, thereby potentially enhancing mechanical fixation of the implant. We wished to determine if using this device improved cement fixation as defined by RSA and gross radiographic appearances at 2 years.

We note several limitations. We observed no difference in translation or rotation as measured by RSA between the two groups (suction versus control). No improvement in cement penetration was proven and there was no difference in the congruency of the cement mantle around the implant. Although we observed more radiolucent lines over a greater percentage of the interface on the 2-year radiographs in the control group the difference was not significant, perhaps owing to a Type II error in data analysis. The loss to followup rate of patients contributed to the low power of this study, and this is its major limitation. In 2002, Berend and Ritter [2] described a different technique of applying suction in the iliac wing but did not report any results. The aspirator retractor, designed in 2000 and used in our series, reportedly improved cement penetration into trabecular bone in one study [17]. Cement penetration greater than 2 mm and an ideal penetration of 3 to 5 mm reportedly produces the strongest cement-bone interface [1, 18, 20]. However, we could not confirm an improvement in cement intrusion in this series. Nonetheless, the mean cement penetration achieved with or without use of suction was in excess of 3 mm in all zones. The maximum penetration desirable is not known.

Few RSA studies compare the effect of different surgical techniques on fixation of the cemented socket. Flivik et al. recently reported the results of a randomized, prospective study comparing a cement finger packing technique with a procedure of sequential pressurization of cement using proprietary pressurizers [10]. There was a difference between the two techniques in rotation around the anteroposterior (Z) axis with the finger-packed cases tilting progressively over a 5-year period to a more horizontal position (mean, 0.8° at 5 years). The pressurized cups rotated slightly into a more vertical position by

Table 6. Number (%) of radiolucencies by zone postoperatively and at 2 years

Group	Number	Postoperatively			2 Years		
		Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
Suction (%)	19	2 (11%)	0 (0%)	1 (5%)	4 (21%)	1 (5%)	3 (16%)
Control (%)	16	5 (31%)	0 (0%)	0 (0%)	10 (63%)	2 (13%)	5 (31%)

Fig. 4 A typical radiographic appearance with good interdigitation of cement with bone and no radiolucent lines is seen on this followup radiograph.

6 months and then stabilized in this position (mean, -0.2° at 5 years). However, there was no difference between the two techniques for migration or rotation around the other axes. The mean proximal migration for all cups was 0.6 mm at 5 years. Onsten et al. reported migration data from a study primarily examining wear rate for cemented and uncemented implants [25]. Again, there were no differences between the two types of socket in migration (confidence interval [CI], -0.14 – 0.46 mm) or rotation (CI, -0.31° – 0.63°). The mean proximal migration at last followup was 0.4 mm in the Charnley cemented socket series. Flivik et al., in their RSA study, examined over a 2-year period, the effect of retaining or removing the subchondral plate before cementation [10]. The only major movement was rotation around the anteroposterior (Y) axis. The removal group stabilized at 12 months in a slightly more vertical position, whereas the retention group rotated slightly, but continuously, into a more horizontal position ($p = 0.04$). We did not find any differences in migration, translation, or angular rotation in our patients. However, the magnitude of proximal migration (0.094 – 0.178 mm) in our series is of the same order of magnitude as that described by Flivik et al. after the same time.

It has been suggested that aseptic socket loosening is governed by the progressive, three-dimensional resorption of bone immediately adjacent to the cement mantle [27]. It also is known a radiolucent line at the biologic interface of the cup is an important prognostic sign for later loosening [12, 16, 26]. The presence of a radiolucent line around the

periphery of the cup implies there is inadequate penetration of bone by cement and in these cases, there may be easier ingress of pressure and debris around the implant to erode bone and compromise fixation. The logical aim of improved techniques is to achieve osseointegration around the whole of the cement-bone interface to seal it from the deleterious effects of fluid flow and debris. The primary effect variable in our series, used for the original power analysis, was proximal migration of the cup. No improvement of fixation was proven from the measured translations and rotations of the socket in the suction group. It may be that in terms of initial fixation, it is difficult to improve on the fixation achieved using well-established contemporary techniques. Some surgeons do not formally pressurize the cement for a prolonged period as has been the practice at Exeter since 1973 [19]. It is possible that the device may confer an advantage when the cementing technique is more rudimentary. In the longer term, it is arguable whether the interface established with the help of the suction device will help prevent access of fluid and pressure to the interface and slow the occurrence of late aseptic loosening.

It could be argued that there have been major advances in cementing techniques in the socket during the past decade, but ultimately only long-term followup will determine whether such methods lead to an increase in longevity of the implant. One reason for this is reoperation for acetabular loosening is rarely necessary within the first 10 years after surgery. Another reason is migration measurements at 2 years, using RSA, have failed in every reported series to show any reduction in migration from these advances. Such lack of migration, shown by RSA at 2 years, normally would indicate (for the cemented femoral component) an extremely favorable long-term outcome for the device, but the same may or may not be the case for the socket. The geometry, surface area, and quality of the interface established cannot be tested by RSA. The most important mechanism of failure of the cemented socket is likely to be the progressive ingress of fluid and debris around the socket margin at the cement bone interface. Stereoradiology is useful to show migration of an implant. If the initial stability of the cup is satisfactory for the imposed loading regime and the eventual mode of failure is unrelated to the initial mechanical fixation, then RSA will not be useful in predicting the eventual fate of the device.

Although we did not observe an advantage of using the suction device using RSA at 2 years, we are hopeful that the device will confer an advantage over a longer time. The sucker aspirator is one of a series of modifications to cementing techniques in the socket being developed at Exeter, and we believe the use of these modifications will substantially improve survivorship of the socket into the second and third decades after implantation.

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References

1. Askew AM, Steege JW, Lewis JL, Ranieri JR, Wixson RL. Effect of cement pressure and bone strength on polymethylmethacrylate fixation. *J Orthop Res*. 1984;1:412–420.
2. Berend ME, Ritter MA. A method for improving acetabular preparation during cemented all-polyethylene acetabular component insertion during total hip arthroplasty. *J Arthroplasty*. 2002;17:782–784.
3. Bland M. *An Introduction to Medical Statistics*. New York, NY: Oxford University Press; 1995.
4. Charnley J. Numerical grading of clinical results. *Low Friction Arthroplasty of the Hip—Theory and Practice*. New York, NY: Springer-Verlag; 1979:20–24.
5. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.
6. Crites BM, Berend ME, Ritter MA. Technical considerations of cemented acetabular components: a 30-year evaluation. *Clin Orthop Relat Res*. 2000;381:114–119.
7. Dawson J, Fitzpatrick R, Carr A, Murray D. Questionnaire on the perceptions of patients about total hip replacement. *J Bone Joint Surg Br*. 1996;78:185–190.
8. DeLee JG, Charnley J. Radiological demarcation of cemented sockets in total hip replacement. *Clin Orthop Relat Res*. 1976;121:20–32.
9. Della Valle CJ, Kaplan K, Jazrawi A, Ahmed S, Jaffe WL. Primary total hip arthroplasty with a flanged, cemented all-polyethylene acetabular component: evaluation at a minimum of 20 years. *J Arthroplasty*. 2004;19:23–26.
10. Flivik G, Kristiansson I, Kesteris U, Ryd L. Is removal of subchondral bone plate advantageous in cemented cup fixation? A randomized RSA study. *Clin Orthop Relat Res*. 2006;448:164–172.
11. Flivik G, Sanfridsson J, Onnerfalt R, Kesteris U, Ryd L. Migration of the acetabular component: effect of cement pressurization and significance of early radiolucency: a randomized 5-year study using radiostereometry. *Acta Orthop*. 2005;76:159–168.
12. Garcia-Cimbrelo E, Diez-Vazquez V, Madero R, Munuera L. Progression of radiolucent lines adjacent to the acetabular component and factors influencing migration after Charnley low-friction total hip arthroplasty. *J Bone Joint Surg Am*. 1997;79:1373–1380.
13. 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.
14. Herberts P, Malchau H. Long-term registration has improved the quality of hip replacement: a review of the Swedish THR Register comparing 160,000 cases. *Acta Orthop Scand*. 2000;71:111–121.
15. Heyse-Moore GH, Ling RSM. Current cement techniques. In: Marti RK, ed. *Progress in Cemented Hip Surgery and Revision*. Amsterdam, The Netherlands: Excerpta Medica; 1982:71–86.
16. Hodgkinson JP, Maskell AP, Paul A, Wroblewski BM. Flanged acetabular components in Charnley hip arthroplasty: ten year follow-up of 350 patients. *J Bone Joint Surg Br*. 1993;75:464–467.
17. Hogan N, Azhar A, Brady O. An improved acetabular cementing technique in total hip arthroplasty: aspiration of the iliac wing. *J Bone Joint Surg Br*. 2005;87:1216–1219.
18. Krause WR, Krug W, Miller J. Strength of the cement-bone interface. *Clin Orthop Relat Res*. 1982;163:290–299.
19. Lee AJ, Ling RS. A device to improve the extrusion of bone cement into the bone of the acetabulum in the replacement of the hip joint. *Biomed Eng*. 1974;9:522–524.
20. MacDonald W, Swarts E, Beaver R. Penetration and shear strength of cement-bone interfaces in vivo. *Clin Orthop Relat Res*. 1993;286:283–288.
21. Majkowski RS, Bannister GC, Miles AW. The effect of bleeding on the cement-bone interface: an experimental study. *Clin Orthop Relat Res*. 1994;299:293–297.
22. Majkowski RS, Miles AW, Bannister GC, Perkins J, Taylor GJ. Bone surface preparation in cemented joint replacement. *J Bone Joint Surg Br*. 1993;75:459–463.
23. Murray DW, Fitzpatrick R, Rogers K, Pandit H, Beard DJ, Carr AJ, Dawson J. The use of the Oxford hip and knee scores. *J Bone Joint Surg Br*. 2007;89:1010–1014.
24. Onsten I, Besjakov J, Carlsson AS. Improved radiographic survival of the Charnley prosthesis in rheumatoid arthritis and osteoarthritis: results of new versus old operative techniques in 402 hips. *J Arthroplasty*. 1994;9:3–8.
25. Onsten I, Carlsson AS, Besjakov J. Wear in uncemented porous and cemented polyethylene sockets: a randomised, radiostereometric study. *J Bone Joint Surg Br*. 1998;80:345–350.
26. Ritter MA, Zhou H, Keating CM, Keating EM, Faris PM, Meding JB, Berend ME. Radiological factors influencing femoral and acetabular failure in cemented Charnley total hip arthroplasties. *J Bone Joint Surg Br*. 1999;81:982–986.
27. Schmalzried TP, Kwong LM, Jasty M, Sedlacek RC, Haire TC, O'Connor DO, Bragdon CR, Kabo JM, Malcolm AJ, Harris WH. The mechanism of loosening of cemented acetabular components in total hip arthroplasty: analysis of specimens retrieved at autopsy. *Clin Orthop Relat Res*. 1992;274:60–78.
28. Söderqvist I, Wedin PA. Determining the movements of the skeleton using well-configured markers. *J Biomech*. 1993;26:1473–1477.
29. Timperley AJ, Howell JR. Implant choice: rational for a flanged socket. In: Breusch SJ, Malchau H, eds. *The Well-Cemented Total Hip Arthroplasty. Theory and Practice*. Berlin, Germany: Springer; 2005:208–213.
30. Valstar ER, Gill R, Ryd L, Flivik G, Borlin N, Karrholm J. Guidelines for standardization of radiostereometry (RSA) of implants. *Acta Orthop*. 2005;76:563–572.