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ACETABULAR BLOOD FLOW DURING TOTAL HIP ARTHROPLASTY

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OBJECTIVE: To determine the immediate effect of reaming and insertion of the acetabular component with and without cement on periacetabular blood flow during primary total hip arthroplasty (THA).

DESIGN: A clinical experimental study.

SETTING: A tertiary referral and teaching hospital in Toronto.

PATIENTS: Sixteen patients (9 men, 7 women) ranging in age from 30 to 78 years and suffering from arthritis.

INTERVENTION: Elective primary THA with a cemented (8 patients) and noncemented (8 patients) acetabular component. All procedures were done by a single surgeon who used a posterior approach.

MAIN OUTCOME MEASURE: Acetabular bone blood-flow measurements made with a laser Doppler flowmeter before reaming, after reaming and after insertion of the acetabular prosthesis.

RESULTS: Acetabular blood flow after prosthesis insertion was decreased by 52% in the noncemented group ($p < 0.001$) and 59% in the cemented group ($p < 0.001$) compared with baseline (prereaming) values.

CONCLUSION: The significance of these changes in periacetabular bone blood flow during THA may relate to the extent of bony ingrowth, periprosthetic remodelling and ultimately the incidence of implant failure because of aseptic loosening.

OBJECTIF : Déterminer l'effet immédiat de l'alésage et de l'insertion du composant cotyloïdien avec et sans ciment sur la circulation sanguine péricotyloïdienne pendant une arthroplastie totale de la hanche (ATH) primitive.

CONCEPTION : Étude clinique expérimentale.

CONTEXTE : Hôpital universitaire de référence pour soins tertiaires de Toronto.

PATIENTS : Seize patients (neuf hommes, sept femmes) âgés de 30 à 78 ans et qui souffraient d'arthrite.

INTERVENTION : ATH primitive élective avec composant cotyloïdien cimenté (huit patients) et non cimenté (huit patients). Toutes les interventions ont été pratiquées par le même chirurgien qui a utilisé une approche postérieure.

PRINCIPALE MESURE DE RÉSULTATS : On a mesuré la circulation sanguine dans l'os cotyloïdien au moyen d'un débitmètre Doppler au laser avant l'alésage, après l'alésage et après l'insertion de la prothèse cotyloïdienne.

RÉSULTATS : La circulation sanguine cotyloïdienne après l'insertion de la prothèse a diminué de 52 % chez les sujets qui ont reçu un composant non cimenté ($p < 0,001$) et de 59 % chez ceux qui ont reçu un composant cimenté ($p < 0,001$) comparativement aux valeurs de base (avant l'alésage).

CONCLUSION : La signification de ces changements de circulation sanguine péricotyloïdienne pendant l'ATH peut être liée à l'étendue de l'interposition osseuse, au remodelage périprothétique et, en fin de compte, à l'incidence de défaillance des implants à cause d'un relâchement aseptique.

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Total hip arthroplasty (THA) is one of the commonest procedures performed by orthopedic surgeons. Acetabular implant stability is a major determinant of the early and long-term success of primary THA. Historically, early stability has been achieved with implants designed to be inserted with cement.[1] Despite improvements in component design and cement technique, however, the rate of loosening of the cemented acetabular prosthesis continues to increase after operation and remains a major cause of THA failure.[2] Published rates of cemented acetabular component loosening range from 19% to 40% at 10 years,[3] and the most recently published 15-year follow-up reported a loosening rate of 22% (26 of 116).[4]

In an attempt to improve on these results, noncemented acetabular components have been used for THA. Although the intermediate results for noncemented acetabular fixation are promising,[2,3] long-term benefits with respect to loosening and osteolysis compared with cemented acetabular components have yet to be determined. Some noncemented prostheses employ pegs, flanges or screws for initial stability and rely on effective interdigitation of the surrounding bone with a porous coating for long-term stability. After insertion of the prosthesis, an inflammatory response leads to a reparative phase with bone remodelling in a process similar to fracture healing that requires an adequate blood supply.[5]

Periprosthetic bone loss is the most common complication of both cemented and noncemented THA[1,6,7] and can lead to implant failure with aseptic loosening.[8] Bone loss may occur in response to stress shielding[1,9,10] or osteolysis with a granulomatous membrane between the implant and bone.[11] The development of osteolysis appears to be related to a number of factors, including the type of implant material, the presence of cement, the size and the volume of particulate debris, as well as to host factors such as the effectiveness of lymphatic drainage and histiocyte response.[11,12] One host factor that has not been investigated is the periacetabular blood supply.

The purpose of this study was to determine the immediate effect of reaming and insertion of the acetabular component with and without cement on periacetabular blood flow during primary THA.

Methods

Patient selection and surgical procedures

In this study, 16 patients underwent 16 THAs. Criteria for inclusion were end-stage arthritis, a consistent prosthetic design for noncemented and cemented prostheses and an identical surgical exposure by a single surgeon. Exclusion criteria included revision arthroplasty, patients with metabolic bone disease, prolonged steroid use or intraoperative hemodynamic instability. The patients were grouped into those undergoing noncemented (8 patients — 4 men, 4 women) and cemented (8 patients — 5 men, 3 women) THA.

The average age of those in the noncemented group was 49.4 years (range from 30 to 63 years) and in the cemented group 73.6 years (range from 67 to 78 years). In all patients the THA was done for arthritis. The diagnosis of patients in the noncemented group was primary osteoarthritis (3), developmental hip dysplasia (3) and avascular necrosis (2). The diagnosis of patients in the cemented group included primary osteoarthritis (6), post traumatic arthritis (1) and rheumatoid arthritis (1). The 2 groups could not be matched for age, diagnosis or comorbidity, so these factors were analysed separately.

All the surgical procedures were carried out at a single institution by a single surgeon. General anesthesia was used, and the patients routinely received preoperative intravenous antibiotics (cephazolin or vancomycin, 1 g). All procedures were performed through a posterior approach to the hip after a complete capsulectomy. Reaming in both groups was performed consistently to the level of bleeding subchondral bone. In the cemented group, the weight-bearing dome was perforated approximately 8 separate times with a 6-mm drill bit to encourage cement interdigitation. The noncemented acetabular prostheses were all St. Michael's cups (Howmedica Inc., Limerick, Ireland), and the cemented acetabular prostheses were all Contemporary cups (Howmedica Inc.).

Bone blood-flow measurement

Acetabular bone blood flow was measured intraoperatively by the PF3 laser Doppler flowmeter (Perimed Inc., Jarfalla, Sweden) by placing a sterilized standard probe perpendicular to and directly on the bone surface. The location of the measurement corresponded to the 12 o'clock position on the acetabular rim. This position was cleared of just enough soft tissue to expose the underlying bone and marked before the first reading to ensure a consistent measurement location over time. Measurements were taken at 3 time points: before reaming (baseline), after reaming, and after insertion of the acetabular component (with or without cement). The operating surgeon was blinded to the results of the blood-flow data for the duration of the operation. The laser Doppler flowmetry (LDF) output was recorded using Perisoft software (Perimed) on a Samsung personal computer for later analysis. After stabilization of the LDF signal demonstrating pulsatile bone blood flow, red cell flux data were averaged over a 10-second period to determine mean flow.

Hemodynamic parameters

At the beginning and end of each surgical procedure the patient's mean arterial blood pressure (diastolic + ⅓[systolic-diastolic]) was recorded. The difference in mean arterial blood pressure from the start to the end of the procedure was calculated for each patient. Any intraoperative complication, such as hemodynamic instability, the need for blood transfusion or fracture, was noted. The patient's preoperative hemoglobin level and the hemoglobin level on postoperative day 1 were recorded, and the change was calculated for each patient. These measurements were monitored to identify any component of hemodynamic instability or anemia acting as a possible confounding variable.

Statistical analysis

All data are reported as mean (and standard error of the mean). Acetabular bone blood-flow data were normalized to pre-reaming values for each patient, and the results for noncemented and cemented arthroplasties were pooled. Analysis of variance (ANOVA) was used to determine if any differences existed between the means of each group before reaming, after reaming and after implant insertion. If ANOVA was significant, the Tukey–Kramer multiple comparisons test was applied. Differences between noncemented and cemented groups at each time point were compared with normalized data using an unpaired *t*-test, with a value of $p < 0.05$ being considered significant. All statistical analysis was performed with the use of Instat2 software (GraphPad Inc., London, Ont.).

RESULTS

Hemodynamic parameters and complications

The mean arterial blood pressure decreased with hip arthroplasty, but there was no significant difference ($p = 0.77$) in the magnitude of this decrease between the noncemented (23 [8] mm Hg) and cemented (20 [5] mm Hg) groups. There was no significant difference ($p = 0.31$) in the mean preoperative hemoglobin level between the noncemented (13.2 [0.5] g/L) and the cemented group (141 [0.7] g/L). The magnitude of the decrease in hemoglobin level in the noncemented group (35 [0.9] g/L) was not significantly different ($p = 0.24$) from that in the cemented group (24 [0.2] g/L). There were no episodes of hemodynamic instability during any of the operations, and no patient needed intraoperative blood transfusion.

Acetabular blood flow

Reaming decreased acetabular blood flow by 34% in the noncemented group ($p < 0.01$) and 38% in the cemented group ($p < 0.01$) compared with baseline values. Insertion of the acetabular prosthesis further decreased blood flow levels compared with post-reaming values in both the noncemented and cemented groups, but this decrease was not statistically significant (Table I). At the end of the operation, after the prosthesis was inserted, acetabular blood flow was decreased by 52% in the noncemented group ($p < 0.001$) and 59% in the cemented group ($p < 0.001$) compared with baseline values (Fig. 1).

Noncemented versus cemented THA

A comparison of the relative effect of the prostheses on acetabular blood flow demonstrated no difference between groups. The perfusion values were reduced to the same extent after reaming ($p = 0.76$) and after prosthe-

Table I

Mean Normalized Acetabular Perfusion During Total Hip Arthroplasty

	Noncemented, $n = 8$		Cemented, $n = 8$	
Measurement time	Mean (and SEM)	*p* value	Mean (and SEM)	*p* value
Baseline	1.00 (0.00)	na	1.00 (0.00)	na
After reaming	0.66 (0.07)	< 0.01	0.63 (0.09)	< 0.01
After implant insertion	0.48 (0.08)	< 0.001	0.41 (0.06)	< 0.001

na = not applicable.

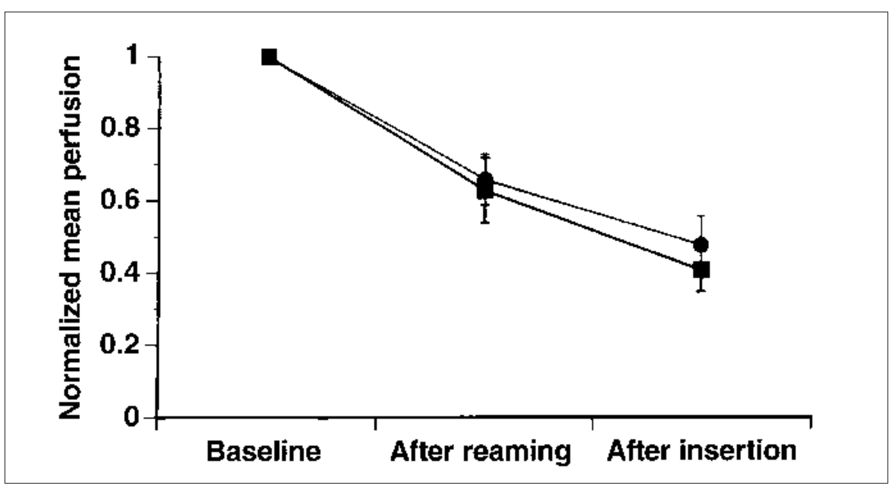

FIG. 1. Normalized mean (and standard error of mean) acetabular perfusion during noncemented (circles) and cemented (squares) total hip arthroplasty.

sis insertion ($p = 0.54$).

Discussion

The optimal method for fixation of the acetabular component in THA remains controversial.[2,13] Concerns over the long-term durability of cemented acetabular components have contributed to an increase in the use of acetabular components designed to be inserted without cement. Aseptic loosening, however, persists as the most problematic complication compromising the results of THA and leading to implant failure.[4,9]

Loosening may result from significant bone loss because of bone remodelling or osteolysis, processes that may in part be related to local blood supply. The effect of acetabular reaming and prosthesis insertion, with and without cement, on acetabular bone blood flow has not been previously investigated. LDF, the method used to measure acetabular blood flow in patients who underwent primary THA, measures red cell flux in a 1- to 3-mm^3 spherical volume around the tip of the probe.[14,15] The selection of measurement location was such that the volume of bone used for measurement surrounding the probe would not be violated by cement interdigitation in the cemented group. LDF has been used both experimentally and clinically to provide real-time, reproducible assessment of bone blood flow, and its advantages include its ability to provide dynamic, in-vivo evaluations without removing tissue, allowing for evaluation of each step involved in the performance of THA.[15,16]

The acetabulum is formed by intramembranous ossification and has an extensive soft-tissue and periosteal blood supply.[17] The primary blood supply of the acetabulum, including the weight-bearing dome, is through the acetabular notch from the acetabular branch of the obturator artery.[18] The inferior gluteal artery supplies the posteroinferior region, and the deep branches of the superior gluteal artery supply the superior region where our measurements were taken.[19] Local blood-flow changes may potentially be an important factor in determining long-term total hip survival by influencing the amount of bony ingrowth and resorption of acetabular periprosthetic bone.[20]

Our study found that the periacetabular circulation was significantly decreased by THA using a noncemented (52%) and cemented (59%) acetabular component. Bone blood flow is significantly decreased by reaming and insertion of the prosthesis compared with pre-reaming levels in both types of procedure. A comparison of the 2 techniques revealed no significant difference in the vascular insult between noncemented or cemented arthroplasty. It must be noted that these groups were not matched for age, diagnosis or comorbidity, which could also affect local blood supply.

The results of our study do not allow us to make a determination as to the cause of the decrease seen in periacetabular blood flow. We may speculate, however, that in both groups the mechanical and thermal insult of reaming may inflict structural injury to surrounding vessels, as well as potentially causing a dynamic decrease in flow due to vasospasm, embolism or thrombosis. In the noncemented group, pressure on the surrounding bone from a tight-fitting component may deform vessels or raise intravascular pressure and impair local blood supply. In the cemented group, the local monomer toxicity and exothermic reaction of methylmethacrylate may have similar deleterious effects on local vasculature and dynamic blood flow.

The clinical importance of the acetabular devascularization demonstrated in our study relates to the effect of blood flow on periprosthetic bone ingrowth and remodelling.

Interdigitation of bone into the porous surfaces of acetabular components designed to be inserted without cement is crucial to component stability.[3] Bony ingrowth depends on blood supply.[5] Conditions or treatments known to have an adverse effect on fracture healing, such as radiation, nonsteroidal anti-inflammatory drugs, and a decreased blood supply, also inhibit bone ingrowth.[5] Fink and associates[21] identified local blood supply as a key factor in determining the extent of bone formation during Ilizarov callus distraction of the tibia.

Also, in a morphometric study of the vascularity of hip arthroplasty periprosthetic tissues, Santavirta and colleagues[22] discovered that vascular injury and decreased blood supply occurred at the implant–host surface, and they implicated this as a cause of insufficient implant osseointegration and prosthetic loosening.

Local vascularity is also important in the successful fixation of acetabular cups inserted with bone cement. The biologic response to the introduction of methylmethacrylate into bone proceeds through 3 distinct phases. Initially, necrosis occurs, lasting up to 3 weeks, and is attributable to mechanical trauma, chemical insult and thermal injury from the exothermic curing reaction.[23] The tissue repair phase is accomplished by granulation tissue, leading to membrane formation and finally mechanical stabilization.[24,25] These processes are necessary for effective interlocking between cement and surrounding bone and rely on an adequate blood supply.

Our study has a number of significant limitations. There exist a number of sources of variability in LDF measurements, including the concentration and velocity of particles, which may have greater importance given the small numbers of subjects in each group. Also, blood-flow measurements were made at only one location in the acetabulum. We chose the 12 o'clock position on the acetabulum to correspond to the posterior-superior quadrant described by Wasielewski and colleagues[26] in 1990 for safe and secure screw fixation of acetabular components. Although adding more sites may minimize variability, the added dissection necessary to circumferentially expose the acetabulum was not surgically indicated by the procedure and may have adversely affected local blood flow. Further research should incorporate multiple blood-flow measurement sites to confirm that the changes seen at this location accurately reflect the rest of the acetabulum, which has different primary sources of vascular supply.

Another limitation is that the measurements were made intraoperatively and immediately after implantation. Since operative measurements may change over time, the duration of the adverse effect on local vascularity should be determined with recovery measurements. More importantly, to assess the clinical significance of the demonstrated changes, a persistent adverse effect on local blood flow must be demonstrated.

To the best of our knowledge, this is the first study in which perfusion of the acetabulum has been quantified during noncemented and cemented THA in humans. The results of our study demonstrate that periacetabular circulation is adversely affected after reaming and immediately after insertion of both noncemented and cemented acetabular components. These changes may ultimately relate to periprosthetic bone loss and the extent of bone ingrowth.

References

1. Harris WH. The problem is osteolysis. *Clin Orthop* 1995;311:46-53.
2. Latimer HA, Lachiewicz PF. Porous-coated acetabular components with screw fixation. Five to ten-year results. *J Bone Joint Surg [Am]* 1996;78(7):975-81.
3. Tompkins GS, Jacobs JJ, Kull LR, Rosenberg AG, Galante JO. Primary total hip arthroplasty with a porous-coated acetabular component. Seven-to-ten-year results. *J Bone Joint Surg [Am]* 1997;79(2):169-76.
4. Madey SM, Callaghan JJ, Olejniczak JP, Goetz DD, Johnston RC. Charnley total hip arthroplasty with use of improved techniques of cementing. The results after a minimum of fifteen years of follow-up [published erratum appears in *J Bone Joint Surg [Am]* 1997;79(4):635]. *J Bone Joint Surg [Am]* 1997;79(1):53-63.
5. Sumner DR, Galante JO. Bone ingrowth. In: Evarts CMcC, editor. *Evarts surgery of the musculoskeletal system*. New York: Churchill Livingstone; 1990. p. 151-76.
6. Jacobs JJ, Galante JO, Sumner DR. Local response to biomaterials: bone loss in cemented femoral stems. *Instr Course Lect* 1992;41:119-25.
7. Rhinelander FW. Effects of medullary nailing on the normal blood supply of the diaphyseal cortex. *Instr Course Lect* 1973;22:161-87.
8. Brown IW, Ring PA. Osteolytic changes in the upper femoral shaft following porous coated hip replacement. *J Bone Joint Surg [Am]* 1985;67:218-21.
9. Dowd JE, Schwendeman LJ, Macaulay W, Doyle JS, Shanbhag AS, Wilson S, et al. Aseptic loosening in uncemented total hip arthroplasty in a canine model. *Clin Orthop* 1995;319:106-21.
10. Jasty MJ, Floyd WE, Schiller AL, Goldberg SR, Harris WH. Localized osteolysis in stable non-septic total hip arthroplasty. *J Bone Joint Surg [Am]* 1986;68:912-9.
11. Maloney WJ, Smith RL. Periprosthetic osteolysis in total-hip arthroplasty: the role of particulate wear debris. *J Bone Joint Surg [Am]* 1995;77:1448-61.
12. Zicat B, Engh CA, Gokcen E. Patterns of osteolysis around total hip components inserted with and without cement. *J Bone Joint Surg [Am]* 1995;77:432-9.
13. Callaghan JJ. Total hip arthroplasty. *Clin Orthop* 1992;276:33-40.
14. Bray R, Forrester K, McDougall JJ, Damji A, Ferrel WR. Evaluation of laser Doppler imaging to measure blood flow in knee ligaments of adult rabbits. *Med Biol Eng Comp* 1996;34(3):227-31.
15. Notzli HP, Swiontkowski MF, Thaxter ST, Carpenter GK 3d, Wyatt R. Laser Doppler flowmetry for bone blood flow measurements: helium-neon laser light attenuation and depth of perfusion assessment. *J Orthop Res* 1989;7(3):413-24.
16. Nilsson GE, Tenland T, Oberg PA. Evaluation of a laser Doppler flowmeter for measurement of tissue blood flow. *IEEE Trans Biomed Eng* 1980;27(10):597-604.
17. Kasselt MR, Whiteside LA, Schoenecker PL, Simmons DJ. Salter innominate osteotomy. The effect of blood supply to the roof of the acetabulum. *Clin Orthop* 1984;183:262-6.
18. Wagner UA, Gembruch U, Fritsch H, Schmitt O, Hansmann M. [Ultrasound anatomy of the fetal hip joint with special reference to the blood supply.] *Ultraschall Med* 1995;16(4):186-91.
19. Itokazu M, Takahashi K, Matsunaga T, Hayakawa D, Emera S, Isono H, et al. A study of the arterial supply of the human acetabulum, using corrosion casting method. *Clin Anat* 1997;10(2):77-81.
20. Engh CA, McGovern TF, Bobyn JD, Harris WH. A quantitative evaluation of periprosthetic bone-remodelling after cementless total hip arthroplasty. *J Bone Joint Surg [Am]* 1992;74(7):1009-20.
21. Fink B, Krieger M, Strauss JM, Opheys C, Menkhaus S, Fischer J, et al. Osteogenesis and its influencing factors during treatment with the Ilizarov method. *Clin Orthop* 1996;323:261-72.
22. Santavirta S, Ceponis A, Solovieva SA, Hurri H, Jin J, Takagi M, et al. Periprosthetic microvasculature loosening of total hip replacement. *Arch Orthop Trauma Surg* 1996;115(2):286-9.
23. Jones LC, Hungerford DS. Cement disease. *Clin Orthop* 1987;225:192-203.
24. Ousterhout DK, Stelnicki EJ. Plastic surgery's plastics. *Clin Plast Surg* 1996; 23(1):183-91.
25. Weber SC, Chapman MW. Adhesives in orthopaedic surgery. A review of the literature and in vitro bonding strengths of bone-bonding agents. *Clin Orthop* 1984;191:249-61.
26. Wasielewski RC, Cooperstein LA, Kruger MP, Rubash HE. Acetabular