The University of Pennsylvania Orthopaedic Journal
14: 55–59, 2001

Suction Instrumentation Decreases Intramedullary Pressure and Pulmonary Embolism during Total Knee Arthroplasty

RENA R. AMRO, M.D.,[2,*] DAVID G. NAZARIAN, M.D.,[1] ROBERT B. NORRIS, M.D., FACC,[3] MATTHEW P. KELLY, M.D.,[4] AND ROBERT E. BOOTH, JR., M.D.[5]

Abstract: The risk of pulmonary embolism as a grave consequence of lower extremity total joint arthroplasty is well documented. Increased intramedullary pressure created during femoral instrumentation has been positively correlated with increased marrow particle content embolization. The purpose of this two part study is to demonstrate that the use of suction devices during femoral canal instrumentation during total knee arthroplasty decreases femoral intramedullary pressure and the amount of marrow content embolized to the pulmonary circulation.

The first phase of the study included 6 fresh frozen complete cadaveric femurs. Three of the distal femurs were instrumented with a standard intramedullary knee alignment guide. The other three femurs were instrumented with the same alignment rod placed inside of a cannulated suction sleeve connected to wall suction (−22 in Hg). Intramedullary pressure was monitored with specialized transducers attached at multiple sites along the specimens. The second phase of the study included 24 patients who underwent unilateral cemented total knee arthroplasty. Twelve randomly selected patients were instrumented with the standard intramedullary guide and twelve patients were instrumented with the suction adapted guide. Transesophageal echocardiography and a computerized pixel counter was used to record and quantify embolic activity intraoperatively in both groups.

The average intramedullary pressures (in Torr) monitored in the cadaveric specimens was 303 with the standard equipment and −248 with the suction device. The group of 12 patients who underwent femoral preparation with the standard equipment exhibited an average of 89 embolic particles registered upon tourniquet release. The average particle count was 31 when the suction equipment was used. Postoperatively, 2 patients in the standard group exhibited transient confusion. The knee scores averages were 89 in both groups and there was no notable radiographic differences at an average of 1-year follow-up.

Although compliance and pressures are different in the cadaver compared to in vivo, the intramedullary pressures in the distal femurs were consistently reduced with use of the suction device. This model allowed measurement at multiple sites to more accurately reflect the pressure changes observed. The device also decreased the number of embolic particles by 65% during knee arthroplasty with no increase in operative time. This data supports the use of these devices to decrease femoral pressure and embolic matter in the pulmonary circulation.

From the [1]Department of Orthopaedic Surgery, University of Pennsylvania Health System, Booth Bartolozzi Balderston Orthopaedics, Pennsylvania Hospital, Philadelphia, [2]Department of Orthopaedic Surgery, University of Pennsylvania Health System, Hospital of the University of Pennsylvania, Philadelphia, [3]Cardiovascular Diseases Division, Pennsylvania Cardiology Associates, Pennsylvania Hospital, Philadelphia, [4]Booth Bartolozzi Balderston Orthopaedics, Pennsylvania Hospital, Philadelphia, and [5]Clinical Professor of Orthopaedic Surgery, University of Pennsylvania Health System, Chief, Department of Orthopaedic Surgery, Pennsylvania Hospital, Philadelphia, PA.

*Correspondence should be addressed to Rena R. Amro, M.D., Department of Orthopaedic Surgery, Hospital of the University of Pennsylvania, 3400 Spruce Street, 2 Silverstein, Philadelphia, PA 19104.

Introduction

The risk of pulmonary embolism as a grave consequence of lower extremity arthroplasty is well documented [15]. A wide spectrum of cardiopulmonary events may result, ranging from tachypnea to sudden cardiac arrest. Post mortem specimen analyses have discovered coagulated blood and fat within the pulmonary vasculature [17]. Embolic material is generated by the activation of Virchow's Triad and an introduction of marrow debris into the venous circulation. Increased intramedullary pressure created while instrumenting the femoral canal has been positively correlated with the amount of embolic material recorded in the pulmonary circulation [17]. The intramedullary alignment systems used to ensure correct position of the femoral component have become a widely accepted technique in knee arthroplasty; however, they typically generate an increase in intra-canal pressure.

Methods devised to reduce intramedullary pressure include overdrilling alignment guide insertion sights, using fluted alignment rods, or avoidance of intramedullary alignment systems altogether [17]. Extramedullary alignment devices also have been shown to decrease pulmonary insult [12]. Additionally, the practice of removing marrow fat and debris with pulsed lavage may further decrease the potential for venous embolism.

Although postoperative pulmonary embolism has been well studied, there are limited studies which document intraoperative embolic phenomena. There is also a paucity of accurate information regarding pressure recordings throughout the length of the femoral canal during instrumentation. The purpose of this two-part study was to evaluate the ability of a suction-adapted intramedullary alignment system to decrease both femoral intracanal pressure and intraoperative pulmonary embolism in comparison to a standard alignment system. Pressure analyses were conducted with a cadaveric model, and transesophageal echocardiography was employed to quantify embolic particles during knee arthroplasty [12,16,17].

Materials and Methods

The first phase of the study incorporated six fresh frozen complete cadaveric femurs which were thawed to room

temperature and prepared by removing the attached soft tissues. An 8-mm drill was used to make an intramedullary-starting hole in the intercondylar notch of the distal femoral specimens. A standard 250 mm, non-fluted, 8 mm diameter, knee intramedullary alignment guide (Zimmer Warsaw, IN) with a rounded tip was used in the control group. The alignment rod was introduced into the distal femoral canal at a similar rate and force as was used in typical knee arthroplasty. A 10 mm diameter, non-fluted cannulated sleeve adapted with a proximal suction port was designed to fit over the standard alignment guide (Fig. 1). The suction sleeve was attached to operating room wall suction (−22 in Hg) in the study group.

Pressure recording was accomplished by inserting pressure transducers (Honeywell, Morristown, NJ) at three separate sites along the distal femur located approximately 8, 16, and 24 cm from the rod insertion site. The transducers were attached to the cortex through ⅛″ drill holes, connected to airtight, saline-filled tubing and calibrated with a pressure recorder. Pressure readings at each of the three-transducer sites were recorded graphically in real time with a computer to document both positive and negative intramedullary pressure changes. Intramedullary pressures were recorded during instrumentation using three complete femoral specimens while using the standard alignment guide and in three different specimens while using the suction adapted intramedullary devices. An average pressure change was calculated from the different transducer sites measured along the canal. The medullary contents were not suctioned prior to instrumentation of the canal.

The second phase of the study involved a clinical trial with 24 patients who underwent unilateral primary cemented total knee arthroplasty. Twelve randomly selected patients underwent knee arthroplasty with an identical intramedullary alignment guide as was used in the cadaveric study. The other twelve patients underwent arthroplasty assisted with the suction adapted alignment guide attached to operating room wall suction (−22 in Hg) (Fig. 2). Embolic activity was quantified intraoperatively in both groups throughout the arthroplasty from before tourniquet inflation until after tourniquet deflation using transesophageal echocardiography (Figs. 3 and 4).

Echocardiography images were obtained during knee arthroplasty using a multiplane transducer unit (Acuson, Mountain View, CA). Baseline images were obtained after the initiation of general anesthesia. The presence of embolic material was sought both in the right heart and inferior vena cava. Images were subsequently recorded during intramedullary instrumentation, during component cementing, and finally after tourniquet release. A filter was used on the intravenous line during the procedure to minimize background artifact caused by microbubbles in the venous sys-

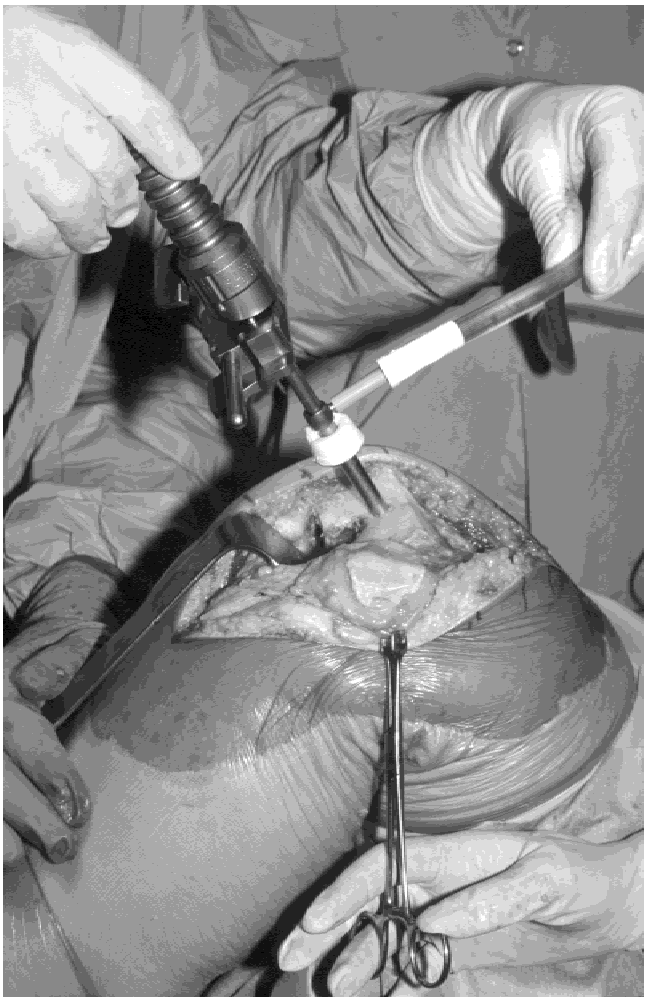

Fig. 2. Suction-adapted instrument attached to wall suction and introduced into the femoral canal.

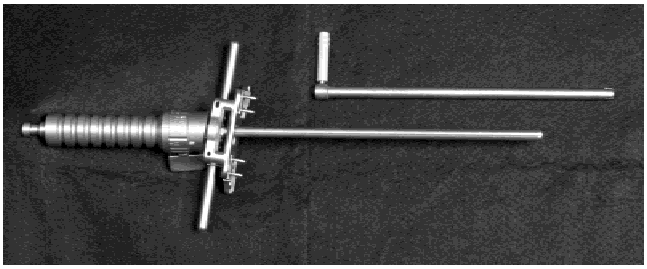

Fig. 1. Standard intramedullary alignment rod (bottom left) with cannulated suction sleeve.

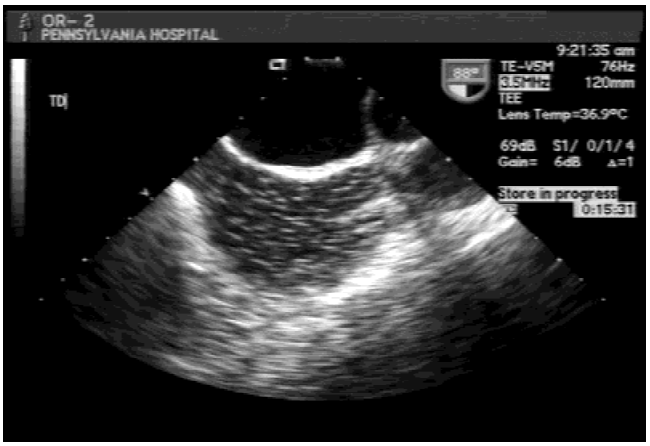

Fig. 3. Transesophageal echocardiogram with substantial embolic activity after tourniquet release in a non-suction case example.

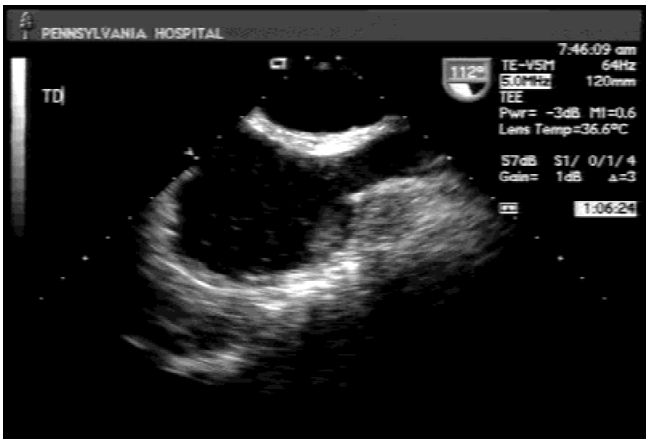

Fig. 4. Significant reduction of embolic material noted when suction-adapted device was used.

tem and right heart. At baseline and again following tourniquet release, additional views were utilized to quantify left ventricular systolic function, to evaluate for significant Doppler abnormalities and any evidence of pulmonary hypertension. Embolic material was evaluated qualitatively by the echocardiographer, who at each stage of the procedure rates the embolic material as none, mild, moderate, or severe. The same echocardiographer was present during all procedures and also reviewed all videotapes. The size of the largest embolus seen after tourniquet release was recorded in each patient.

Quantitative analysis was performed using an image processing package (NIH Image), similar to the approach taken by Morawa [12]. Digitized images were obtained at each stage of the procedure and were chosen to display what was expected to be maximal embolic material at those stages in all cases. Frames ($\frac{1}{30}^{th}$ second) were selected, and after choosing a circumscribed area of interest (the right atrium or inferior vena cava), the particles were counted. Only particles of two or more pixels were included, while densities adjacent to walls were eliminated in order to decrease the effects of artifact. The optical density of the area of interest was also measured, which displayed no embolic material as nearly black with a density value close to zero, while a completely filled chamber was nearly white with a density close to 100. The optical density of the left atrium was also calculated to serve as a measure of background. Since these echocardiographic images tend to show some embolic material in a clustered pattern, it was felt that optical density may be a more accurate reflection of embolic activity than a particle count in some patients. Three frames were selected for analysis in each view of a chamber, and the results averaged.

Patients were evaluated clinically and radiographically according to the Knee Society scoring systems [7,10]. Mixed model analysis of variance techniques (ANOVA) were used to statistically test the difference between the use of suction and non-suction devices during instrumentation of the cadaveric femurs. This same model was used to assess the statistical difference between the average particle densities in the suction and non-suction groups during arthroplasty.

Results

The first phase of the study involved a comparison of femoral instrumentation of cadaveric femurs with and without suction adaptation. The average pressure measured in the three transducers in the control group of femurs during instrumentation was 303 mm Hg (range 24–920) and −248 mm Hg (range −103 to −325) in the suction group. All of the femurs instrumented with suction equipment exhibited negative ambient pressure.

The second phase of the study, performed during knee arthroplasty, compared the average embolic particle densities and particle counts. The average density was 20.6 (range 6.2–56.8) in the non-suction arthroplasty group and 7.9 (range 6.2–56.8) in the suction adapted instrument group. The average particle counts were also higher in the non-suction group (avg. 89, range 32–141) compared to the suction group (avg. 31, range 12–62). The differences in both the cadaveric and clinical studies were noted to the statistically significant ($p < 0.001$).

The average range of motion was 2°–114° and the average Knee Society scores were 89 in the entire group of 24 knees. There was no significant difference noted between either group. The average postoperative anatomic angle was 4° valgus in the entire group, again with no differences noted between the two groups.

Complications included one hematoma in the non-suction group and one superficial wound dehiscence in the suction group. There were two cases of postoperative confusion which resolved before discharge in two non-suction patients and no cases occurred in the suction group.

Discussion

The merits of intramedullary and extramedullary femoral alignment during total knee arthroplasty have become an area of controversy amongst othopaedic surgeons. Tillet found that appropriate equivalent alignment was obtained using either intramedullary or extramedullary instrumentation [18]. Other studies have shown statistically significant improvement in accuracy of femoral cuts created when intramedullary instrumentation was used [5]. This potential for greater accuracy and ease of use has made the intramedullary alignment systems more popular with knee surgeons worldwide [3]. The intramedullary guides, however, unlike extramedullary alignment systems necessitate marrow cavity trespass which increases the pressure generated within the medullary canal.

Increased intramedullary pressure during total knee arthroplasty has been shown to exacerbate embolization of marrow elements [2,17]. A positive correlation exists between the rise in intramedullary pressure and the amount of bone marrow fat extravasation [11]. Instrumentation of the medullary cavity can extrude marrow contents into the perifemoral venous circulation [15]. Whitenack and Hausberger

found that a 50 to 100 mm H_2O increase in pressure in the tibial medullary space of rabbits was sufficient to produce pulmonary embolization of medullary contents [19]. The current study has demonstrated that adapting a femoral intramedullary guide with a suction sleeve can lower the ambient pressure within the intramedullary space. This negative pressure creates a reverse gradient to potentially blunt the extrusion of marrow contents into the efferent vasculature. Also, removing the amount of marrow contents from the medullary space further reduces the potential for marrow extravasation and particle emboli into the pulmonary circulation.

Ries has shown that a relatively small increase in intramedullary alignment rod volume may substantially increase intramedullary pressure [17]. The larger instrument volume creates a higher local pressure phenomenon, which may theoretically crush marrow and intramedullary debris against the endosteal wall. Although the volume of the suction-adapted equipment in this study was greater than the standard non-suction-adapted equipment, a decrease in pressure measurement was recorded in each of the specimens at all three transducers sites. These findings suggest that perhaps the pressure gradient between the intramedullary and extramedullary spaces during instrumentation has a more profound effect on embolism than the marrow expansion seen with a slightly more voluminous alignment rod.

Pressure previously measured in the supracondylar region of the femur during knee arthroplasty may underestimate the maximum intramedullary pressure when the rod is inserted close to the femoral isthmus [8]. Thus, it was elected to analyze pressure at three separate sites along the femoral canal to more accurately assess the pressure changes at different depths of rod insertion. Although pressure and compliance changes in cadaveric marrow are different than in vivo, this model was used because of the technical difficulties encountered with measuring pressure at multiple sites along the femur during live human arthroplasty. The average pressure measured were elevated in all of the standard specimens 303 mm Hg and significantly decreased in all of the suction specimens (−248 mm Hg).

Severe cardiovascular depression during total knee arthroplasty can result from pulmonary embolism which has been reported in 1 to 5% of cases [1,8,13]. Fat embolism can cause hypoxia, hypotension, and occasionally sudden death [4,8,12,17,20]. There have been several reported deaths after the use of an intramedullary alignment rod to assist knee replacement. These patients were found to have extensive fat emboli in the lungs and brain at autopsy [20]. In a series of 292 patients, severe hypotension developed in fourteen, which resulted in five cardiac arrests [9]. Autopsy in this group also revealed fat emboli in the lungs of the patients who died shortly after the arthroplasty.

Several physiologic measures have been utilized to monitor hemodynamic changes during intramedullary instrumentation during total knee arthroplasty. Fahmy has demonstrated a decrease in arterial blood-oxygen tension, oxygen saturation, end-tidal carbon dioxide tension, arterial blood pressure, and heart rate immediately after insertion of a femoral alignment rod [8]. Caillouette also reported on a near fatal case of fat embolism syndrome as measured by oxygen saturation, which began immediately after intramedullary femoral rod placement [4]. Other methods include pulmonary artery pressures and oxygen tension gradients which are more invasive and only indirect measures of embolic activity.

Transesophageal echocardiography has been described as an accurate quantitative measure of embolic material during total knee arthroplasty [12]. Current echocardiographic techniques, however, do not accurately distinguish tissue characterization of the embolic material; any material differing in density from blood will produce echoes [16]. An increase of echogenic signals appears during orthopaedic procedures when the femoral medullary canal is invaded [14]. Substantial amounts of embolic particles have been shown with echocardiography during the course of knee arthroplasty when performed with intramedullary instrumentation [12]. Furthermore, a significant decrease in embolic material was observed when extramedullary instrumentation was used [12]. Similarly, the current study reveals a large amount of embolic debris with intramedullary instrumentation as observed by transesophageal echocardiography.

If intramedullary alignment systems are the preferred method for knee arthroplasty, the data generated from this study suggests that simultaneously attaching a suction device can significantly reduce embolic activity. A reduction of debris may therefore lower the hemodynamic risks leading to cardiopulmonary or neurologic sequelae. Although no psychometric tests were employed in the study patients, two patients in the non-suction group exhibited transient confusion postoperatively while there were no cardiovascular or neurologic complications seen in the suction device group.

There were no significant differences noted in operative times, accuracy of alignment or postoperative clinical scores between the study and control groups. The average knee scores were 89 in both groups and there was no notable radiographic difference at an average one-year follow-up.

These findings further substantiate that a decrease in intramedullary pressure correlates with a reduction of embolic activity. The authors conclude that if intramedullary instrumentation is to be utilized during total knee arthroplasty then a suction device may be added to the intramedullary rod during canal instrumentation to decrease the amount of embolic debris.

References

1. Adams JH, Grama DI, Mills E, Sprunt TG: Fat embolism and cerebral infarction after use of methylmethacrylic cement. *British Med J* 3:740–741, 1972.
2. Agnew SG: Intramedullary Reamer Redesign: The effect on pressure and temperature. *Techniques in Orthopaedics* 13:9–14, 1998.
3. Bargren JH, Blaha JD, Freeman MAR: Alignment in total knee arthroplasty. *Clin Orthop* 173:178–183, 1983.
4. Caillouette JT, Anzel ST: Fat embolism syndrome following the in-

tramedullary alignment guide in total knee arthroplasty. *Clin Orthop* 251:198–199, 1990.
5. Cates HE, Ritter MA, Keating EM, Faris PM: Intramedullary versus extramedullary femoral alignment systems in total knee replacement. *Clin Orthop* 286:32–39, 1993.
6. Dola RS, Inglis AE, Lewis RJ: Fat embolism following bilateral total knee replacement with the guepar prosthesis. A case report. *Clin Orthop* 115:195–198, 1976.
7. Ewald FC: The knee society total knee arthroplasty roentgenographic evaluation and scoring system. *Clin Orthop* 248:9–12, 1989.
8. Fahmy NR, Chandler HP, Dnaylchuk K, Matta EB, Sunder M, Siliski JM: Blood-gas and circulatory changes during total knee replacement. *J Bone Joint Surg* 72A:19–26, 1990.
9. Guepar et al: Guepar Hinge Prosthesis. Complications and results with two years' follow-up. *Clin Orthop* 248:112–119, 1989.
10. Insall JN, Dorr LD, Scott RD, Scott WM. Rationale of the knee society clinical rating system. *Clin Orthop* 248:13–14, 1989.
11. Kropfl A, Davies J, Berger U, Hertz H, Schlag G: Intramedullary pressure and bone marrow fat extravasation in reamed and unreamed femoral nailing. *J Ortho Res* 17:261–268, 1999.
12. Morawa LG, Manley MT, Edidin AA, Reilly DT: Transesophageal echocardiographic monitored events during total knee arthroplasty. *Clin Orthop* 331:192–198, 1996.
13. Orsini EC, Richards RR, Mullen JB: Fatal fat embolism during cemented total knee arthroplasty: a case report. *Canadian J Surg* 29: 385–386, 1986.
14. Parmet JL, Horrow JC, Berman AT, Miller F, Pharo G, Collins L: The incidence of large venous emboli during total knee arthroplasty without pneumatic tourniquet use. *Anesthesia Analogues* 87:439–44, 1998.
15. Parmet JL, Horrow JC, Pharo G, Collins L, Berman AT, Rosenberg H: The incidence of venous emboli during extramedullary guided total knee arthroplasty. *Anesthesia Analogues* 81:757–762, 1995.
16. Parmet JL, Horrow JC, Singer R, et al: Echogenic emboli upon tourniquet release during total knee arthroplasty: pulmonary hemodynamic changes and embolic composition. *Anesthesia Analogues* 79:940–5, 1994.
17. Ries MD, Rauscher LA, Hoskdins S, Lott D, Richman JA, Lunch F: Intramedullary pressure and pulmonary function during total knee arthroplasty. *Clin Orthop* 356:154–160, 1998.
18. Tillett ED, Engh GA, Peterson T: A comparative study of extramedullary and intramedullary alignment systems in total knee arthroplasty. *Clin Orthop* 230:176–181, 1988.
19. Whitenack SH, Hausberger FX: Extravasation of fat from the bone marrow cavity. *Am J Pathol* 65:335–345, 1971.
20. Zimmerman RL, Kroner LF, Blomberg DJ, Nollet DF: Fatal fat embolism following total knee arthroplasty. *Minnesota Med* 66:213–216, 1983.