Enhancing Femoral Cement Fixation in Total Knee Arthroplasty

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Abstract: Several factors have been shown to be associated with early development of radiolucent lines at the bone-cement interface in total knee arthroplasty (TKA). The posterior condylar surfaces, in particular, seem subject to poor cement technique, which could lead to early loosening. This study compares two cementation techniques in TKA, with respect to depth of cement penetration and radiolucency in the posterior condyles. All penetration depths were greater in group I (injected) versus group II (noninjected). Sixty-seven percent of group I showed penetration depths >1.5 mm compared with 23% of group II. No specimen in group I had gaps in the cement mantle on visual inspection or radiolucency on radiographic evaluation. No statistical differences, however, could be demonstrated between the two groups. **Key words:** bone-cement interface, radiolucency, cement penetration depth, total knee arthroplasty, cement, fixation, posterior condylar surface.

In general, the posterior condylar surfaces in total knee arthroplasty (TKA) are subject to poor cement technique. The exposure and access are relatively difficult, and it is more difficult to clean the bone surface with pulsatile lavage. Component design also contributes to this problem in many, if not most, designs. The posterior cuts for the femoral component may be unique compared with the other cuts. At implantation, the component moves parallel to the cut surface. The fit is close, and, thus, there is no active intrusion mechanism for the cement initially placed on the component. Cement placed first onto the bone is pushed to the back of the knee by the close-fitting component. All other surfaces have an angular relationship, some perpendicular *component* to the direction of implantation, which contributes to active intrusion of cement into the cancellous bone. This situation is most obvious for the distal femoral and proximal tibial surfaces. As well, it is clearly seen on the chamfer cuts. Furthermore, in essentially all modern component designs, the anterior cut is angled so that placement of the femoral component pushes some cement directly into cancellous bone.

King and Scott [1] noticed a disproportionately high rate of lucency at the posterior femoral bone cement interface. They hypothesized that early loosening of cemented femoral components resulted from poor support of the prosthetic posterior condyle (zone 4). They suggested that poor cementing technique, inaccurate bone cuts, and deficient bone stock from persistent synovitis were responsible.

Others have shown that blood and debris weaken the bone-cement interface [2,3], that tensile and

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Submitted January 23, 2002; accepted July 5, 2003.
No benefits or funds were received in support of this study.
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0883-5403/03/1808-0006$30.00/0
doi:10.1016/S0883-5403(03)00450-9

shear strengths of the interface are related to cement penetration depth [3], that pressure injection of cement results in better penetration depth [3,4], and that penetration depth of ≤1.5 mm is associated with early development of radiolncent lines at the bone-cement interface [5].

The underlying hypothesis of this study is that cement placed on the posterior surface of the femoral component, one that has essentially line-to-line bony fit at its margins, does not actively become intruded or injected into the posterior cancellous bone. Furthermore, unless a surgeon not only applies cement to the surfaces, but also actively injects the cement into the posterior cancellous surface, one cannot expect maximal or optimal intrusion. Even applied cement, unless specifically injected, will be pushed posteriorly and peripherally as the femoral component is positioned. Again, there seems to be no active intrusion of cement sitting on bone or on a component whose movement is parallel to the bone surface, especially if the outer edge of the component will push/plow away the cement. This hypothesis has been tested in a sawbones model.

Materials and Methods

This study compares two cementation techniques in TKA with respect to depth of cement penetration and radiolucency in the posterior condyles (zone 4). This area of the bone-cement interface was specifically chosen because, as mentioned, these surfaces are cut parallel to the direction of implantation, and access to adequately cleanse the bone with pulsatile lavage is typically difficult, making these surfaces particularly prone to poor cement penetration compared with other surfaces.

A total of 12 sawbones femurs (Pacific Research Laboratories, Inc., Vashon Island, WA), size medium-left, were divided into two groups of six. The particular sawbones chosen had a subsurface quality and texture very closely matching the structure of distal femoral cancellous bone. Standard arthroplasty cuts were performed on each distal femur using the intramedullary guide and medium-sized cutting blocks for the Duracon Total Knee System (Howmedica, Rutherford, NJ). Simplex P (Howmedica) polymethylmethacrylate (PMMA) bone cement was prepared by mixing for 90 seconds in a standard Stryker High Vacuum Cement Injection System (Stryker Corp., Kalamazoo, MI) under a vacuum of 22 in Hg. Room temperature was maintained between 65° and 67°F for all samples. For the six specimens in group I (injected), the cement was pressure-injected 3 minutes after initiation of mixing, in a low-viscosity state, using a 65° angled pressure injector (Stryker Corp.) and cement gun (Fig. 1). The particular angled injection nozzle used was specifically directed for the purpose of active injection into the posterior femoral cut surfaces.

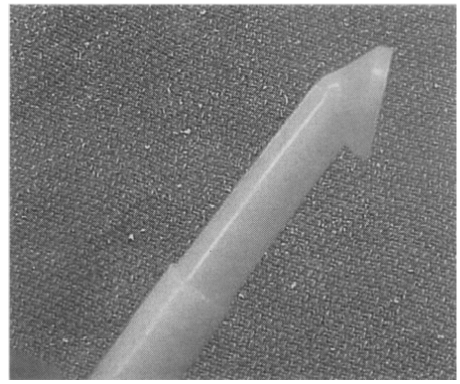

Fig. 1. Stryker 65° angled pressure injector.

Three minutes later, the cement was applied, in a doughy state, to a standard Duracon nonporous coated plastic duplicated femoral component (Medical Accessories & Research, Inc., Zeeland, MI), size medium-left, including the posterior flange. The plastic component then was impacted onto the distal femur in the usual fashion. A proximally directed force, in line with the longitudinal axis of the femur, was maintained until the cement dried. In group II (noninjected), the cement was applied to the cut surfaces using a cement gun, without pressure injection, 3 minutes after initiation of mixing. The "treatment difference" between group I and group II is that a specifically angled injector was used, while the cement was in a low-viscosity state, for intentionally actively injecting cement into the posterior femoral cut surfaces.

All specimens were evaluated radiographically at the posterior interface in the lateral plane to evaluate cement penetration.

After radiographic evaluation, the medial and lateral condyles of each specimen were sectioned in the sagittal plane, perpendicular to the joint line, into three portions measuring approximately 7 to 8 mm in thickness. Each section was labeled for identification. For example, in group I, specimen 1, the medial condyle, medial section would be labeled I-1-M-M, the central section labeled I-1-M-C, and so on. Two sections in group II (II-1-M-M and II-2-M-M) were damaged during the sectioning process and were not included in further analysis. The bone-cement interface of each specimen was divided into zones as described by Ewald [6], then

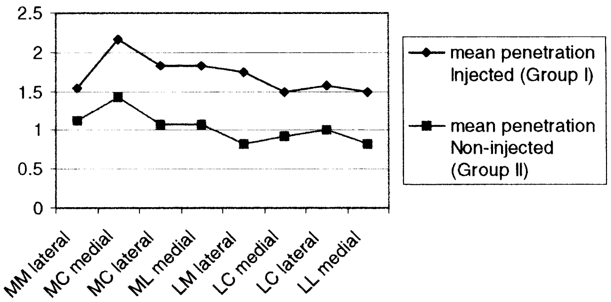

Fig. 2. Mean cement penetration depths in millimeters.

evaluated under 18× power using a dissecting microscope. Cement penetration depth in zone 4 was measured in millimeters on the medial and lateral sides of each section. The mean cement penetration depth in zone 4 was calculated for the medial and lateral sides of each section of each specimen. The difference in mean penetration depth (δM) was calculated by subtracting the average in group II from group I. A positive number indicated deeper mean penetration for a specimen in group I compared with group II. Statistical analysis was performed using SPSS 9.0. Statistical significance was calculated using the Mann-Whitney test. For both groups, measurement of cement penetration for the medial condyle, medial section, medial side, and lateral section, lateral side, was not performed. Similarly, measurement was not performed for the lateral condyle, medial section, medial side or lateral section, lateral side. These areas represented cross-sections of the medial and lateral edges of the component and sawbones condyles, where there was no cancellous structure, as a result of being the cortical margins of the condyles.

Results

In group I, medial condyle, the mean cement penetration in the medial section, lateral side was 1.54 mm; the central section, medial side was 2.17 mm; the lateral side was 1.83 mm; and lateral section, medial side was 1.83 mm. For the lateral condyle, the mean penetration in the medial section, lateral side measured 1.75 mm; the central section, medial side was 1.50 mm; the lateral side was 1.58 mm; and the lateral section, medial side was 1.50 mm. In group II, medial condyle, the mean cement penetration in the medial section, lateral side was 1.12 mm; the central section, medial side was 1.42 mm; the lateral side was 1.08 mm; and the lateral section, medial side was 1.08 mm. For the lateral condyle, medial section, lateral side, depth averaged 0.83 mm; the central section, medial side averaged 0.92 mm; the lateral side averaged 1.00 mm; and the lateral section, medial side averaged 0.83 mm.

All mean cement penetration depths in group I were greater than in group II (Fig. 2).

In group I, 11 of 48 measurements made were <1.5 mm. In group II, 31 of 46 measurements were <1.5 mm.

The means and associated *P* values for the medial and lateral sides of each section of each specimen are listed in Table 1. Statistically significant differences were found in two sections: the medial condyle, lateral section, medial side and the lateral condyle, central section, lateral side (P = .044, 0.025, respectively).

In group I, the cement was pressure-injected 3 minutes after initiation of mixing in all specimens.

All specimens in groups I and II showed some degree of inaccuracy with the bone cuts at the posterior condyles when examined under the microscope. Only specimens in group II, however, were observed to have areas lacking cement between the plastic component and sawbone surface in this region. No specimens in group I showed this finding.

Radiographically, three specimens in group II had radiolucencies in zone 4. None were >1 mm. Only in group II, specimen 2, did the radiographic findings correlate with the microscopic findings. No specimen in group I had lucency in the posterior condyles.

Discussion

Radiolucency at the bone-cement or bone-component interface does not necessarily mean loosening of the component and has not been proven to

Table 1. Mean Differences Between Groups I and II and Associated *P* values

Location	ΔM	*P* value
MM lateral	0.42	.449
MC medial	0.75	.123
MC lateral	0.75	.139
ML medial	0.75	.044*
LM lateral	0.93	.054
LC medial	0.58	.134
LC lateral	0.58	.025*
LL medial	0.67	.082

*Statistically significant.

be a problem clinically. However, it can be viewed as a less-than-optimal situation. Wright et al [7] studied 114 hybrid TKAs (uncemented femur, cemented tibia). Although 30% of the femurs had radiolucency in at least one zone (six in zone 4), none were >1 mm and none were considered loose. They noted, however, a 6% incidence of moderate discomfort. Conversely, King and Scott [1] identified 15 patients with loose cemented femoral components. In 13 of 15 patients, the radiolucency was first seen in zone 4. Of these 13, 8 had radiolucencies apparent immediately after surgery. They hypothesized that early loosening of cemented femoral components resulted from poor support of the prosthetic posterior condyle caused by inaccurate surgical cuts, poor cementing technique, and deficient bone stock from persistent synovitis. At 90° of flexion, there are compressive forces applied across the posterior condyles of the femur. With proper cement technique, these forces are transmitted directly to the bone-cement interface in zone 4. However, with poor cementation, the forces are transmitted to the distal and anterior interfaces in the form of shear and tensile forces, respectively. All of the specimens had some degree of inaccuracy in the bone cuts of the posterior condyles. However, none in group I had gaps in the cement mantle.

Only one specimen in group II had radiolucency that correlated with microscopic findings of gaps in the cement mantle. One explanation is that gaps in the cement mantle may not be contiguous, but the difference in density where cement is lacking could result in increased penetrance of the radiographic beam, manifested as a radiolucency. Because the specimens were sectioned in 7- to 8-mm portions, it is possible that a gap in the cement mantle is within a specimen. This is true, obviously, for both groups. No specimen in group I, however, had radiolucencies or gaps in the cement.

There should be a limit to the depth of penetration one attempts to achieve for two reasons. First, the polymerization of PMMA is a highly exothermic reaction. Increased temperature at the bone-cement interface may result in bone necrosis, predisposing the interface to failure. Huiskes and Sloof [8] showed that the maximal temperature increase in bone during cement polymerization is dependent on the depth of penetration. This may account for the radiolucencies that develop over time in cemented components. Second, as the depth of cement penetration increases, so does the potential for bone loss at the time of revision surgery.

Walker et al [5] showed that cement penetration of 2 mm or more correlated with a stable bone-cement interface at 2 years and penetration of 1.5 mm or less usually led to radiolucency. The posterior condyles showed poor penetration. They recommended a penetration depth of 3 to 4 mm to avoid possible thermal necrosis and contact with weaker bone at greater depths.

Of all the measurements made in group I, only 23% were <1.5 mm compared with 67% in group II. The average cement penetration depths for specimens in the pressure-injected group were all at least 1.5 mm.

Timing is also a key issue with respect to pressure-injecting cement. Studies have shown that injection of cement in a low-viscosity state may improve penetration into bone. Markolf and Amstutz [4] showed that penetration of cement into cavities was better at 4 minutes after initiation of mixing than at 6.5 minutes. Furthermore, high-pressure, short-duration pressurization was more effective for 1-mm and 2-mm cavities. Walker et al [5] recommended applying the cement to bone no more than 4 to 5 minutes after mixing for bone with average porosity, longer for more porous, shorter for more dense. All pressure injecting was performed 3 minutes after initiation of mixing when the cement was at low viscosity.

There are several issues regarding the design of this study that deserve further discussion. We chose to use sawbones for a number of reasons. One is availability. The plastic-duplicated femoral components only were available in size medium-left. The sawbones were more readily obtainable than cadaver legs of the same size and side.

Another is consistency. When using cadaver specimens, differences in bone porosity and quality are variables to control. This would have been done by performing the two different cement techniques on a cadaver's left and right knee. However, because the plastic components only were available for the left side, this was not possible. Because the production of the sawbones is standardized, this variable is lessened to a certain degree. Furthermore, according to the manufacturer, and corroborated by visual inspection, the sawbone femurs mimic the properties of human cancellous bone.

A third consideration is cost. One cadaver leg is approximately $150 compared with about $20 for one sawbone femur. For a single specimen or for the total number of specimens used here, this cost would not seem to be an issue. However, when we consider the variability in human bone and begin to multiply by the number of specimens necessary to get meaningful averages, we have not only increased the work load substantially, but the cost as well, and would be living with the additional source of greater variability.

Increased room temperature can speed the curing of PMMA. This factor can impact the cement viscosity at the time of injection, even with standardized times. The room temperature in this study was maintained between 65° and 67°F, similar to standard operating room temperature.

Variability can be introduced through multiple examiners. In this study, a single examiner, using the same ruler, measured all the specimens with 18× magnification.

It is important to recognize that this study still consisted of small samples with relatively large variability. Statistical differences were calculated using the Mann-Whitney test, a nonparametric alternative to the Student *t*-test used for small samples with large variability. The Mann-Whitney test has approximately 90% power compared with the Student *t*-test.

The mean penetration depths between the two groups, with the exception of two, did not differ significantly. Although no statistical significance was found among the majority of the means, there was a trend for deeper penetration of cement in zone 4 with pressure injection, and this may be clinically significant as far as potential loosening is concerned.

Despite theoretical and even practical drawbacks of this study, and although there was no statistically significant differences demonstrated between the two groups, we feel that direct pressure intrusion of cement to this type of surface, one in which the seating of the component is not specifically pushing cement into the cancellous bone, gives a more consistent and reproducible cement mantle, as demonstrated by a lack of visually detected gaps and radiographic radiolucencies, as well as more frequent penetration to >1.5 mm. Furthermore, we are alerting the surgeon to the general situation of such surfaces. Many surgeons may avoid placing cement on them because one sees most of it being pushed away, sometimes to regions difficult or impossible to clear. Furthermore, many of these surfaces are ones that are particularly difficult to pressurize directly. The most obvious surfaces with this characteristic in knee arthroplasty are the posterior cuts on the femur and the vertical surfaces of the channels prepared for cylindrical tibial stems.

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