Heat Generated With Pegged or Keeled Glenoid Components Fixed With Defined Amounts of Cement

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abstract

Glenoid component loosening is a common complication of total shoulder arthroplasty and has been associated with the progression of radiolucent lines at the glenoid bone-cement interface. Generation of heat during the exothermic reaction of cement curing may cause osteonecrosis of bone, potentially leading to the development of radiolucent lines. The purpose of this study was to measure the heat generated with various defined amounts of cement used for glenoid component fixation.

Ten fresh-frozen cadaver scapulas were randomized to receive a keeled or pegged component with 1, 2, 3, 5, or 7 g of cement for fixation. An infrared camera was used to record the surface temperature generated during the cement curing process to an accuracy of ±2.0°C. Computed tomography was used to evaluate the cement mantle. The maximum temperatures generated did not exceed the critical value for osteonecrosis (56°C) in any of the specimens. The 4 specimens without a complete mantle were those fixed with a smaller quantity of cement (1, 2, or 3 g), and the largest cement mantle thicknesses were observed with the use of 7 g of cement.

Up to 7 g of cement can be used without significant concern for thermal necrosis. Incomplete cement mantles were observed when ≤3 g of cement was used for fixation. Our results suggest that surgeons should use >3 g of cement to avoid incomplete cement mantles and that up to 7 g of cement can safely be used for glenoid component fixation.

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Figure 1: Photograph of 10-mL syringes filled with different amounts of cement.

Figure 2: Photograph of the infrared camera being held in place while the cement cured.
Glenoid component failure is the most common complication following total shoulder arthroplasty.1 Radiolucent lines at the bone–cement interface of glenoid components were first described in 1982 by Neer et al2 and have been reported to occur at a rate of 10% to 94% following total shoulder arthroplasty.1,3 Progression of these lines seems to correlate with symptomatic loosening.6,7 Radiolucent lines have been proposed to occur as a result of poor cementing technique,4 mismatch between the polyethylene insert and the glenoid surface,4,8 poor glenoid preparation that prevents adequate seating of the component,1 and thermal necrosis of bone.9

In a cadaveric glenoid component cementing study, Churchill et al9 observed temperatures in excess of the known threshold for bone necrosis. Because polymethylmethacrylate (PMMA) cures via an exothermic reaction,11 the use of large quantities of cement may increase the risk of thermal necrosis of bone.

The purpose of this study was to (1) identify the amount of cement that can safely be used without exceeding the known threshold for bone necrosis, (2) identify any difference in temperatures generated based on type of glenoid implant (keeled or pegged), and (3) evaluate the completeness and thickness of the cement mantle with various quantities of cement.

**Materials and Methods**

Ten fresh-frozen cadaver scapulas were thawed to room temperature and dissected free of all soft tissue. Five female and 5 male specimens ranged in age from 62 to 92 years. No specimen demonstrated gross evidence of glenohumeral osteoarthritis. The specimens were randomized to receive a medium keeled with a 51-mm-diameter curvature (Aequalis Spherical Glenoid System; Tornier, Saint-Ismier Cedex, France) or a 48-mm pegged with a 54-mm-diameter curvature glenoid component (Affinity Glenoid System; Tornier) with 3 peripheral pegs and a larger, fluted central peg. After creating a hole in the center of the glenoid, hand and power reaming were performed until all cartilage was removed and a concentrically prepared surface was achieved. Preparation of the peripheral peg holes or keel slot was performed using standard instrumentation. The specimens were thoroughly irrigated using 0.9% normal saline to clear any debris. The trial glenoid component was impacted in place to assure that it was well seated on the prepared glenoid surface. Each component was then fixed with 1, 2, 3, 5, or 7 g of cement (Simplex P; Stryker, Kalamazoo, Michigan) (Figure 1). The cement was prepared according to the package directions and weighed using a digital scientific balance (Scout Pro; Ohaus, Parsipany, New Jersey) that recorded masses in grams to the nearest 10th of a gram. The cement was hand mixed in a bowl and placed in a 10-mL syringe. For the pegged glenoid components, the 3 peripheral holes were dried, and care was taken to deliver an approximately equal dose of cement to each of these holes. No cement was placed around the central fluted peg. For the keeled components, the vault was dried and the entire volume of cement was delivered. For specimens with greater amounts of cement, care was taken to compress all cement into the keel or peg holes with no extrusion of cement.

The specimens were then placed in a heated, insulated terrarium equipped with a thermometer capable of recording the temperature in centigrade to the 10th decimal place. Testing did not commence until an ambient temperature of 30°C to 40°C had been achieved to simulate physiologic conditions. An infrared thermography camera (ThermoVision A20M; FLIR, Wilsonville, Oregon) with an accuracy of ±2°C was placed at 1 end of the terrarium. A hole was cut in the screen and insulation to accommodate the camera lens. A clamp was used to secure the specimens so that the face of the glenoid was directed in line with the camera lens (Figure 2). The specimens were monitored as the excess cement from the same batch cured and hardened. The temperatures were recorded in minute intervals until the cement was completely hardened, which took an average of 12 minutes (Figure 3). Based

![Figure 1: Photograph of 10-mL syringes filled with different amounts of cement.](image1)

![Figure 2: Photograph of the infrared camera being held in place while the cement cured.](image2)
on defined parameters set by Eriksson and Albrektsson, bone is at risk for thermal necrosis when the temperature is $>56^\circ\text{C}$ instantaneously, $>50^\circ\text{C}$ for 1 minute, or $>47^\circ\text{C}$ for 5 minutes.

**Radiographic Analysis**

Axial computed tomography (CT) scans (Siemens Sensation 64; Siemens Ag, Washington, DC) were obtained for all specimens using 0.4-mm incremental slices. Sagittal reformatted images of the glenoid fossa and coronal reformatted images of the long axis of the scapular body were obtained. A musculoskeletal fellowship-trained radiologist (I.M.O.) blinded to the amount of cement used in each specimen made all radiographic measurements and assessments. The maximal cement mantle thickness was measured on axial and sagittal reformatted images. Whether a complete cement mantle existed around each individual peg or keel was also documented.

**Statistical Analysis**

The difference between experimental groups was determined using 2-way analysis of variance (ANOVA) with the component type (pegged or keeled) and the amount of cement as the 2 factors. Post-hoc $t$ tests were used to determine $P$ values comparing keeled and pegged components for each amount of cement. No adjustment was made for multiple testing. An ANOVA model was used to analyze the data comparing cement mantle size. In our analysis, $P<.05$ was considered significant. All data were analyzed using SAS statistical software (SAS Institute Inc, Cary, North Carolina).

**RESULTS**

No recorded temperature for any specimen met thresholds for thermal necrosis of bone ($>56^\circ\text{C}$ instantaneously, $>50^\circ\text{C}$ for 1 minute, or $>47^\circ\text{C}$ for 5 minutes). The maximum temperatures recorded were $32.6^\circ\text{C}$ for 1 g keeled and $29.0^\circ\text{C}$ for 1 g pegged, $38.1^\circ\text{C}$ for 2 g keeled and $36.0^\circ\text{C}$ for 2 g pegged, $34.2^\circ\text{C}$ for 3 g keeled and $34.7^\circ\text{C}$ for 3 g pegged, $38.9^\circ\text{C}$ for 5 g keeled and $44.8^\circ\text{C}$ for 5 g pegged, and $48.3^\circ\text{C}$ for 7 g keeled and $37.6^\circ\text{C}$ for 7 g pegged.

The average temperatures calculated for the keeled and pegged specimens are shown in Table 1. For the 1-, 2-, and 3-g specimens, no difference existed in average temperatures generated. The average temperature for the 5-g pegged specimen was $39.7^\circ\text{C}$ vs $31.2^\circ\text{C}$ for the 5-g keeled specimen ($P<.0001$). The average temperature for the 7-g pegged specimen was $33.2^\circ\text{C}$ vs $36.8^\circ\text{C}$ for the 7-g keeled specimen ($P=.0020$). When the data for the pegged and keeled specimens were combined, the average generated temperatures of the 1- vs 2-g specimens ($P<.0001$) and the 3- vs 5-g specimens ($P<.0040$) were different (Table 2). No difference existed between the 2- vs 3-g ($P=.1300$) or 5- vs 7-g specimens ($P=.5200$).

The combined cement mantle thickness (axial and sagittal measurements for pegged and keeled specimens) was 3.70 mm for 1-g, 5.43 mm for 2-g, 5.85 mm for 3-g, 6.68 mm for 5-g, and 8.03 mm for 7-g specimens ($P=.0090$). Four speci-
ments had incomplete cement mantles: 1-, 2-, and 3-g keeled and 3-g pegged (Figure 4). No specimen that received 5 or 7 g of cement had an incomplete cement mantle.

**Discussion**

Radiolucent lines at the cement–bone interface after prosthetic glenoid component placement have occurred in 10% to 94% of patients. Although the clinical importance of these lines has been debated, the progression of these lines is a sign of radiographic component loosening. Churchill et al proposed that these lines may be secondary to thermal necrosis of bone secondary to the exothermic reaction of PMMA. In their study, 12 of 17 specimens exceeded temperatures known to induce thermal necrosis of bone. They used various quantities of cement (range, 2.65-8.08 g) for glenoid component fixation. In contrast, we used defined amounts of cement (range, 1-7 g) to fix keeled or pegged components.

The findings of the current study differ from those of Churchill et al in that no specimen exceeded the 56°C critical threshold for thermal necrosis of bone, despite our using up to 7 g of cement. We attempted to use a setup similar to the one presented by Churchill et al so that our results would be comparable, but several differences may account for the different findings. Churchill et al used DePuy CMW 3 cement (Raynham, Massachusetts), whereas we used Stryker Simplex P cement. Although both products are PMMA, subtle differences in chemical properties may have affected the maximum temperatures generated. In addition, the accuracy of the infrared thermography cameras used in our study was ±2.0°C, whereas Churchill et al’s was ±0.05°C. This is unlikely to have been a factor because none of our temperatures would meet criteria for thermal necrosis if increased by 2°C. Finally, Churchill et al used curettes to remove cancellous bone from the glenoid and base of the coracoid during preparation of the glenoid. This was not performed on our specimens and may account for the differences in maximum temperature detected by the infrared camera.

The current study identified no consistent difference in terms of temperature generated based on the type of glenoid component (keeled or pegged) implanted. The 1-, 2- and 3-g specimens demonstrated no difference in average temperature generated between the keeled and pegged specimens. The 5-g specimens demonstrated a difference, with the pegged specimen having an average of 39.7°C vs 31.2°C for the keeled specimen ($P<.0001$). Although the pegged specimens had a higher average temperature at the 5-g cement dose, this difference did not persist when evaluating the 7-g cement dose. The average temperature for the 7-g pegged specimen was 33.2°C vs 36.8°C for the keeled specimen ($P=.002$). Churchill et al identified a trend in which lower maximum temperatures were observed in the pegged group, but this difference was not statistically significant.

The current study found that larger cement mantles were observed with larger volumes of cement used. Specimens fixed with smaller volumes of cement (1-3 g) were likely to have incomplete cement mantles. These incomplete mantles may compromise early fixation, allow for micromotion, lead to formation of radiolucent lines, and ultimately allow for component fixation failure. However, specimens using 5 or 7 g of cement had complete cement mantles.

Our study has several important limitations. First, the cadaver model used does not account for factors that could potentially decrease the maximum temperature generated in vivo, such as blood flow. Second, only surface temperatures were measured with the infrared camera, and the use of a deeper thermocouple may have increased the accuracy of our measurements. Third, we used 1 type of cement, and thus the findings may not be applicable to other manufacturer’s products. Fourth, we did not account for the size of the glenoid vault or the porosity of the cancellous bone, both of which could influence temperatures generated by the cement. In addition, 1 specimen was used in each group, and the data may have been more accurate with more specimens in each group. Finally, other actions, such as reaming and drilling, may put glenoid bone at risk for thermal necrosis during total shoulder arthroplasty.

**Conclusion**

The results of our study demonstrate that up to 7 g of cement can be used for
glenoid fixation without reaching critical temperatures for bone necrosis. In addition, the study demonstrates that $>3$ g of cement is necessary to ensure a complete cement mantle around a keeled or pegged glenoid component. Based on these findings, 5 to 7 g of cement may be the optimal amount of cement for all-polyethylene glenoid component fixation.

**References**


