Mechanical Stability of Total Hip Replacement Using Pressurization of Bone Cement During Curing: Push-out Tests in Cadaver Femora

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abstract

An experimental model was used to assess the mechanical stability of a cemented hip prosthesis, comparing the result from applied pressurization versus its absence during the curing process. Twelve pairs of cadaveric femora underwent simulated total hip replacement. The right femurs were pressurized for 10 minutes in the upper surface of the construct. The applied pressure was 325,4 KPa. All the femurs were osteotomized 30 days postoperatively and push-out tests were performed. The mean failure load at the cement-bone interface was found to be 58% higher with the pressurization technique (7.619 KN versus 4.817 KN) ($P<.001$). The amount of pressure we used proved advantageous, however the required physical effort proved exhausting. The design of a new surgical instrument could resolve the problem in the future.

The application of acrylic bone cement (polymethylmethacrylate) has been documented as a successful mode of fixation in total hip replacement (THR). Many aspects of the cementing technique have been investigated such as variations of the cement itself, different modes of application, as well as variations of implant design, to increase survivorship of the artificial joint.[1-8] Pressurization of bone cement during curing in THR is an important step of the procedure.[9-12]

No specific data exists in the literature with respect to the way, duration, and amount of the pressurization is required. Additionally, no instrument exists that provides reproducible results; and the current outcome is based on the physical effort that the surgeon is able to exert intraoperatively. Therefore pressurization techniques are empirical more so than evidence based. In this study, we performed in vitro push-out tests on cadaveric femurs under specific and realistic conditions to investigate the factors that contribute to the stability of the construct.

Materials and Methods

Twelve pairs of cadaveric femurs were used. Preoperative templating was performed using the Multilock templates (Zimmer). All femurs were osteotomized according to the current technique. The femoral canal was prepared using the broaches and the associated instrumentation from the Zimmer Multilock Hip System.

CMW-1 radiopaque bone cement (DePuy) was used in the second generation cement technique (intramedullary plug and cement gun, conventional open bowl mixing technique). Aluminum rods of 15-cm length with a circular cross section were used to simulate the stem. After introduction of the stem and during cement curing, pressure was applied on the upper surface of the right femurs for 10 minutes. Start time commenced 1.5 to 2 minutes following mixing; the femoral cement compressor (Smith and Nephew)

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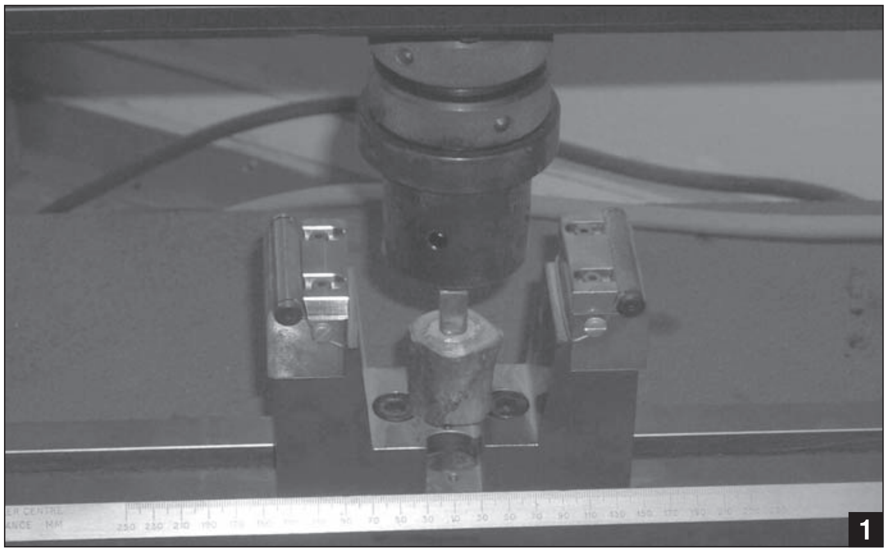

Figure 1: The constructs were subjected to push-out mechanical loading with an Istron 4482 cervomachine. The pusher of the cervomachine was slightly smaller from the cross section of the aluminum rod for the interface of stem-cement to be evaluated.

was used only for the right femurs. The applied force was 147.15 N (15 Kg).

The cementing technique was repeatedly evaluated radiographically. Fundamental inclusion criteria was the presence of an at least 2-mm thick cement mantle.[5,13] Following preparation, the specimens were kept in a dark room with steady temperature of 21°C over 30 days, for completion of cement polymerization.

The specimens then were sectioned in 6 pieces, using a precision water cooled rotating diamond disk cutting device (Discotom). The first cut was 1.5 cm below the calcar osteotomy. The following 4 consecutive sections each were 3-cm thick, and the last 1 encountered the remaining bone. The proximal slice was excluded from the study due to the irregular filling of the femoral canal; and the same applied to the distal piece because it consisted of a very small part of the aluminum rod, the cement restrictor, and 1 piece of cement that filled the entire lumen. Finally 48 specimens representing each technique were left to be tested.

The constructs were subjected to push-out mechanical loading with an Istron 4482 cervomachine, to evaluate the strength of the bone-cement and cement-stem interface (Figure 1). Stainless steel pushers were used. The stresses at the tested interface were rising, followed by an abrupt decrease of their value; and this was considered the failure point of the construct. This point represented the peak of the load/displacement graph created by the computer connected to the cervomachine.

The results were statistically analyzed using the two-way analysis of variance test with SNK multiple comparisons.

Results

The mean value of the cement-bone interface failure load was 4.817 KN for the unpressurized technique and 7.619 KN for the pressurized technique (58% increase of the failure load). The difference was statistically significant $P<.001$. The mean failure values for the stem-cement interface were 1.851 KN for the first technique and 2.139 KN for the second (15% increase of the failure load), however the difference was not statistically significant at the 95% level of significance (Figure 2).

Discussion

Polymethylmethacrylate is the most widely used nonmetallic biomaterial in THR since the days of sir John Charnley.[14-16] Since then many efforts have been made to increase its mechanical strength and durability.

Applied pressure on the bone cement during curing is known to ameliorate its mechanical properties in cement specimens.[17] Cement pressurization is believed to reduce air inclusions and monomer evaporation thus increasing the final poly-

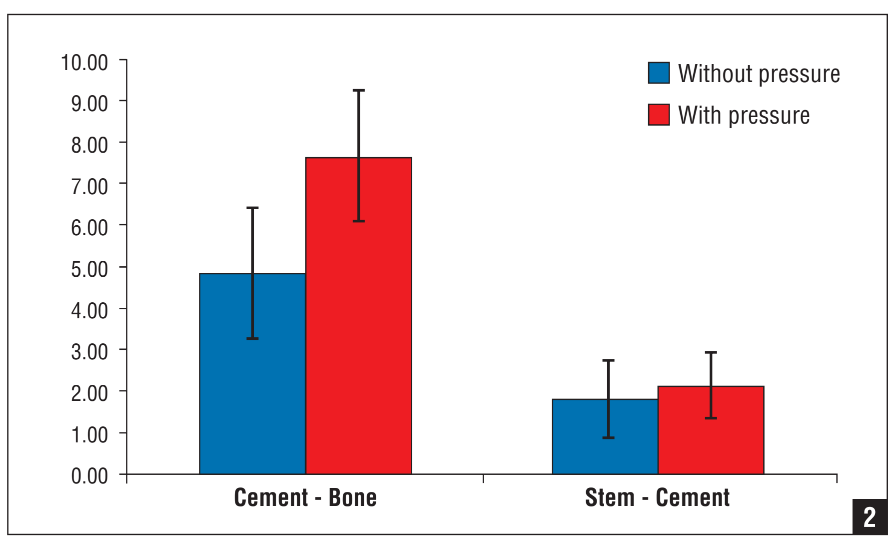

Figure 2: Mean values, expressed in KN and standard deviation (SD) of the failure load, in the push-out tests performed, between the two groups studied. The statistical significance was 99% ($P<.001$).

mer density and decreasing the porosity of the cement.[18]

In clinical practice, acquired high pressure of the cement during insertion is one of the goals of the third generation cement technique, as described by Harris and Davies.[19] This results in increased interdigitation of bone-cement interface, reduced mixing of blood with the bone cement, reduced porosity as well as optimized mechanical properties of the bone cement that further ameliorates the longevity of THR.[16,19-25]

There is a consensus that only high-viscosity cements be used with pressurized technique in vivo because high viscosity prevents deep penetration into cancellous bone.[26,27] Deep penetration would deprive parts of the trabecular system of its blood supply. Furthermore high viscosity cement is low in free monomer and therefore is responsible for less systemic adverse effects. It also is commonly used in surgery. CMW-1 radiopaque cement, which is commonly used in tests, was used in our study.[28] The push-out tests were performed on the 30th day for optimal polymerization of the bone cement.[29]

Pressurization is a process of major importance [9-12,30,31] and problems with its application have been identified:

- There are no specified recommendations based on experimental studies regarding its duration.
- There are no specified recommendations regarding the amount of the applied pressure that could maximize the mechanical stability of the construct by minimizing possible complications resulting from high-pressure values such as fat embolism or fracture of the femur.
- There is no standardized way of applying a specified given value.
- The application of a certain pressure is not possible and therefore reproducible.
- The physical effort that a surgeon can apply is variable depending on his /hers physical strength.

A surgical instrument that has been designed to address all these problems will be presented in the near future.[32]

A selected pressure of 325.4 KPa was used in vitro to counterbalance the reverse effects of high pressure, such as the femoral fractures, especially in osteopenic patients, thus creating strong constructs. Pressure of 300 KPa is considered to be necessary to achieve 3 to 5 mm of cement intrusion into trabecular bone.[31] The amount of pressure used was well tolerated in our study and no complications were observed. To achieve continuous constant pressure after the insertion of the femoral stem, a closed system should be created that would prevent the bone cement extraction from the proximal femur during curing. The introduction of an instrument-tensioner could be the solution to this problem.

Related articles have been published on the use of either 3000 N of pressure, pressure that is unlikely to be used,[27,33] or the thumb pressure technique [34] (approximately 100 KPa) described by Charnley.[14-16] The use of a proximal centralizer also has been used to increase the cement pressurization particularly in the proximal femur.[35] In another study, 3 different femoral cement pressurization techniques were compared in vitro (standard, pressurizer in situ, and thumb pressurization) using proximal and distal pressure transducers. In these techniques no pressure was applied on the upper surface of the constructs after the insertion of the stem. The standard technique produced an optimum pressure of above 100 KPa over a longer period.[36]

The shear strength forces at the stem-cement interface, although found to be higher, using the pressurization technique were not found to be statistically significant at the 95%, which could be due to the smooth surface of the aluminium rods.

A complication related to this technique is pulmonary embolism.[37] However, surgical tips that could reduce this complication, have been described.[38]

Improvement of the current instrumentation is a prerequisite of a good cementation technique, therefore further research is needed.

What is already known on this topic

- Pressurization results in increased interdigitation of bone-cement interface, reduced mixing of blood with the bone cement, reduced porosity, and optimized mechanical properties of the bone cement that further ameliorates the longevity of total hip replacement (THR).
- No data existsin the literature with respect to the way, duration, and amount of pressurization required. No instrument exists that could provide reproducible results; the current outcome is based on the physical effort that the surgeon is able exert.

What this article adds

- Pressurization of bone cement during curing caused more stable constructs in a cemented THR simulator. The mean failure load at the cement-bone interface was found to be 58% higher with the pressurization technique (7.619 KN versus 4.817 KN) ($P<.001$).
- The specific amount of pressure we used proved advantageous; however the required physical effort was exhausting. The design of a new surgical instrument could possibly resolve this problem.

Conclusion

Pressurization of bone cement during curing caused more stable constructs in a cemented THR simulator. The amount of pressure we used proved advantageous, however the required physical effort was exhausting. The design of a new surgical instrument could possibly resolve this problem.

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