HIGH BONE CEMENT PRESSURIZATION IS ACHIEVED DURING FEMORAL STEM INSERTION INTO VISCOUS CEMENT

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Introduction: An important component of modern bone cement technique in total hip arthroplasty is pressurization of the cement after it has been loaded into the femoral canal. Pressurization induces flow of the cement into the trabecular spaces. This interdigitation improves the shear strength of the cement/bone interface and presumably lessens the probability of loosening and subsequent failure. Optimal interdigitation can be identified radiographically by the characteristic "white-out" appearance in which the bone/cement interface cannot be readily distinguished.

Several authors have advocated the use of low viscosity bone cement (or equivalently, cement in the early stage of its cure cycle) since it can theoretically flow more easily into the trabecular pores under any given pressure. We argue, however, that superior cement mantles can be achieved with high viscosity cement (or equivalently, cement late in its cure cycle).

It is typically assumed that effective cement pressurization can be obtained using a cement gun. We believe, however, that in practice only low pressures can be developed in this manner. As soon as any pressure is developed, the cement simply extrudes through imperfections in the proximal seal and distal plug thereby releasing the pressure. Using low viscosity cement, which can escape easily, exacerbates this condition. The hypothesis of this work is that high cement pressures are developed during insertion of the femoral stem into the cement filled canal. These pressures are much higher than those achieved by use of the cement gun. Stem insertion causes displacement of the cement in the canal, forcing it to flow proximally out the narrow gap between the cortex and the stem. This results in cement pressurization. We further hypothesize that these cement pressures will be higher if the stem is inserted into more viscous cement as compared to less viscous cement (ie., later in the cure cycle vs. early in the cure cycle). The objective of this work was to carry out a controlled in-vitro experiment in which the cement pressure developed at a selection of locations along the femoral canal was measured directly during femoral stem insertion.

Methods: An in-vitro model system was used to measure intramedullary bone cement pressure developed during femoral stem insertion. A simulated femoral canal (non-porous) was fabricated by machining an appropriately shaped cavity out of a block of aluminum. The distal end of the cavity was sealed representing a perfect distal canal plug. Flash diaphragm pressure transducers were mounted at four locations equally spaced along the medial canal wall to measure cement pressures at these locations (Proximal, Mid-Prox, Mid-Dist, Distal). Two femoral stem designs were considered: Straight having a uniform anterior/posterior dimension, and Tapered having an increased A/P dimension proximally. The canal wall was shaped such that a uniform 2mm thick mantle around the tapered femoral stem was produced. When the straight stem was used this resulted in a 1mm thicker mantle proximally along the anterior and posterior walls.

Two cement viscosity conditions were considered: Low (130,000 centi-Poise) corresponding to an early point in the cure cycle (ie., "runny"), and High (285,000 centi-Poise) corresponding to late in the cure cycle (ie., "doughy").

For each experimental run a double batch of Simplex P (Howmedica) bone cement was vacuum mixed for 90 seconds. Ten cc of cement was injected into the reservoir of a capillary rheometer, and the remainder injected into the femoral canal. The capillary rheometer continuously measured the viscosity of the cement throughout its cure cycle. When the target viscosity (High or Low) was reached, the femoral stem was inserted into the canal at a uniform rate of 10mm/sec using a servo-hydraulic materials testing machine. Cement pressures at each of the four canal locations, cement viscosity, stem position, and stem insertion force were all recorded continuously throughout the run.

The area under each cement pressure vs. time trace was calculated (pressure x time). This quantity is proportional to the amount of cement flow that would be expected to occur under the measured conditions. Two-way ANOV was used to compare groups.

Results: For each viscosity/stem combination, the highest cement pressures were always reached in the distal canal location, while the lowest were found proximally (Fig 1). Inserting the stem late in the cement's cure cycle (High viscosity) generated significantly higher pressure x time values at all measured locations within the cement mantle as compared to the Low viscosity condition (Tab. 1). The tapered stem generated higher pressure x time values than the straight stem. This was likely due to the thinner cement mantle it produced proximally along the anterior and posterior surfaces.

Table 1. Time integrals of cement pressures at each canal location.

<table>
<thead>
<tr>
<th>Viscosity/Stem</th>
<th>Proximal</th>
<th>Mid-Prox.</th>
<th>Mid-Dist.</th>
<th>Distal</th>
</tr>
</thead>
<tbody>
<tr>
<td>High / Taper</td>
<td>5</td>
<td>623 ± 88</td>
<td>5257 ± 602</td>
<td>7870 ± 834</td>
</tr>
<tr>
<td>High / Straight</td>
<td>4</td>
<td>291 ± 80</td>
<td>2094 ± 290</td>
<td>3602 ± 630</td>
</tr>
<tr>
<td>Low / Taper</td>
<td>5</td>
<td>176 ± 49</td>
<td>1311 ± 228</td>
<td>2205 ± 500</td>
</tr>
<tr>
<td>Low / Straight</td>
<td>5</td>
<td>129 ± 24</td>
<td>1180 ± 117</td>
<td>1854 ± 193</td>
</tr>
</tbody>
</table>

Figure 1. Example of Pressure vs. Time data for one representative run.

Discussion: Insertion of the femoral stem generated high cement pressurization when performed late in the cement's cure cycle. The highest absolute pressures (up to 2200 kPa) were developed distally. These pressures are significantly higher than can be achieved with a cement gun (50-100 kPa).

In evaluating the effectiveness of cement pressurization, the duration of pressurization is as important as the magnitude of the pressures developed. This is reflected by the pressure x time quantity. A very high pressure that is maintained only instantaneously may not result in as much cement flow as a lower pressure maintained for a longer duration. Although higher viscosity cement requires higher pressure in order to flow, these results suggest that, on balance, the higher viscosity cement driven by the higher pressures developed during stem insertion may yield improved interdigitation.

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