PULL-OUT STRENGTH OF SCREWS FROM POLYMETHYL METHACRYLATE CEMENT

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We aimed to determine the optimal method of inserting a screw into polymethylmethacrylate (PMMA) cement to enhance fixation. We performed six groups of ten axial pull-out tests with two sizes of screw (3.5 and 4.5 mm AO cortical) and three methods of insertion. Screws were placed into ‘fluid’ PMMA, into ‘solid’ PMMA by drilling and tapping, or into ‘curing’ PMMA with quarter-revolution turns every 30 seconds until the PMMA had hardened. After full hardening, we measured the maximum load to failure for each screw-PMMA construct.

We found no significant difference in the pull-out strengths between screw sizes or between screws placed in fluid or solid PMMA. Screws placed in curing PMMA were significantly weaker: the relative strengths of solid, fluid and curing groups were 100%, 97% and 71%, respectively. We recommend the use of either solid or fluid insertion according to the circumstances and the preference of the surgeon.

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Recent advances in orthopaedics have increased the use of screws placed in polymethylmethacrylate cement (PMMA) to enhance fixation. The best method of inserting these screws into PMMA has not been resolved. Possible methods include: insertion into fluid PMMA which is then allowed to harden around the screw; into solid PMMA after drilling and tapping; or into curing cement with slow tightening of the screw as the cement hardens.

There are many reports of the pull-out strength of screws from bone (Frandsen, Christoffersen and Madsen 1984; Zindrick et al 1986; Daum et al 1988; Iversen et al 1988) and from various anatomical sites (Frandsen et al 1984; Zindrick et al 1986; Daum et al 1988; Iversen et al 1988), but few about the use of screws in PMMA. Sim, Daughtery and Ivins (1974) and Harrington et al (1976) showed that PMMA enhanced fixation after resection of bone for neoplasms.

Our computer search of the literature found only one paper which addressed the pull-out strength of screws from PMMA. Cameron et al (1975) studied four states: fluid, solid, early curing and late curing. They concluded that “the screw should be inserted into fluid PMMA and the PMMA allowed to cure with no further manipulation”. We had some doubts about the methods used by Cameron et al, and therefore performed a new study.

MATERIALS AND METHODS

We carried out approximately ten tests in each of six situations, using either 3.5 mm or 4.5 mm AO cortical screws (Synthes, Paoli, Pennsylvania) with hexagonal heads, machine screw shafs, buttress threads, and nonsel-fee tips inserted into PMMA (Surgical Simplex P: Howmedica, Rutherford, New Jersey) in fluid, solid or curing states. In the ‘fluid’ group, the screw was inserted as soon as possible after the PMMA mix became fluid and the cement was allowed to harden around the screw. In the ‘solid’ group, the screw was inserted at least one day after curing, by the standard AO techniques of drilling, tapping and screwing. We used a new tap after every five specimens to ensure consistent cutting. In the ‘curing’ group, the screw was inserted as soon as possible after the PMMA mix became fluid and then turned at least one-quarter revolution every 30 seconds until the PMMA had hardened.

We used a casting mould machined from a 6061 aluminium block, filled when the last remaining powder monomer polymerised. A screw was inserted perpendicularly according to the group of the test and the mould was removed after full hardening. The thickness of the PMMA blocks was such that five full threads were held: 7.5 mm for the 3.5 mm screws, and 10 mm for the 4.5 mm AO screws (Fig. 1). Testing of the screw-PMMA construct was performed at least one day later to allow consistent curing times.
The axial pull-out strength of each screw-PMMA construct was tested on a universal testing machine (Instron Corporation, Canton, Massachusetts, or MTS Systems Corporation, Minneapolis, Minnesota). The axis of loading was that of the long axis of the screw and the rate was 10 mm/min. A force-displacement curve was recorded for each construct, with particular note of the maximum load.

The maximum load for each specimen was entered into the Minitab statistical analysis computer program (State College, Pennsylvania) and significant differences between the fluid, solid and curing groups were determined for each screw size by both two-sample and analysis-of-variance tests.

RESULTS

The maximum load for each specimen, and the mean and standard deviation for each of the six groups are shown in Table I. The main finding was that for both screw sizes the maximum load was clearly greater in the fluid and solid groups than in the curing group. Results were consistent, the smallest standard deviation being for the solid group.

Data from ten of the specimens which fractured through the PMMA, rather than failing at the screw-PMMA interface, have been excluded from the table. Inclusion of these data, however, made no significant change to the results. Two-sample and analysis-of-variance tests gave similar results for the two screw sizes, with no significant difference between the use of fluid and solid PMMA (Table II). Screws placed in curing PMMA were significantly weaker than those placed by the other two methods. The load-displacement curves and the manner of breakdown were characteristically different between groups, as shown in Figures 2, 3 and 4.

DISCUSSION

There are three possible mechanisms of failure when a metal screw is pulled out of PMMA by a purely axial load (Fig. 5):

1) The screw shaft may fail, in which case the critical dimension is its cross-sectional area (which depends on its core diameter), and the critical material property is the tensile strength of the metal.

2) The screw threads may fail, in which case the critical dimension is the root area of the screw thread (which depends on the core or inner diameter of the screw and the base of the thread) and the critical material property is the shear strength of the metal.

3) The PMMA may fail. The critical dimension is then the root area of the tapped thread (which depends on the

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**Table I.** Maximum load (N) at failure for each specimen, with means and sd for each group, excluding suspect data (see Results)

<table>
<thead>
<tr>
<th>Specimen</th>
<th>3.5 mm screw</th>
<th>4.5 mm screw</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solid</td>
<td>Fluid</td>
</tr>
<tr>
<td>1</td>
<td>3395</td>
<td>3419</td>
</tr>
<tr>
<td>2</td>
<td>3730</td>
<td>3871</td>
</tr>
<tr>
<td>3</td>
<td>4077</td>
<td>3537</td>
</tr>
<tr>
<td>4</td>
<td>3561</td>
<td>4397</td>
</tr>
<tr>
<td>5</td>
<td>3666</td>
<td>3006</td>
</tr>
<tr>
<td>6</td>
<td>3663</td>
<td>3748</td>
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<td>8</td>
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<tr>
<td>9</td>
<td>3361</td>
<td>3411</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mean for</td>
<td>3605</td>
<td>3574</td>
</tr>
<tr>
<td>group</td>
<td>255</td>
<td>413</td>
</tr>
</tbody>
</table>

**Table II.** Significance of differences between groups according to two-sample tests given as p values

<table>
<thead>
<tr>
<th></th>
<th>Solid</th>
<th>Fluid</th>
<th>Curing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td></td>
<td>0.61*</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>Fluid</td>
<td>0.30†</td>
<td></td>
<td>0.0003†</td>
</tr>
<tr>
<td>Curing</td>
<td>&lt; 0.0001†</td>
<td>&lt; 0.0001*</td>
<td>-</td>
</tr>
</tbody>
</table>

* 3.5 mm screws
† 4.5 mm screws
outer diameter of the screw and indirectly on the crest width) and the critical material property is the shear strength of the PMMA (Oberg and Jones 1968; Frankel and Burstein 1970; Hughes and Jordan 1972; Gozna 1982).

In our study, the screw never failed; the PMMA failed every time. The materials which we used in each specimen were identical, and the only variable was the manner of insertion. We were therefore measuring the effect of the manner of screw insertion on the shear strength of the surrounding PMMA.

There were two differences in our study from that of Cameron et al (1975). First, we had no failures through the screw threads, even during preliminary testing in which loads of over 10 000 N were generated. Cameron et al found that screw threads failed at approximately 750 kg (or 7350 N). It is possible that screw geometry or materials have changed since 1975. Secondly, they tested.
only five specimens in each group and presented the results and their conclusion without statistical analysis.

We used both 3.5 mm and 4.5 mm screws to determine whether the optimal method of insertion varied with screw size. We took care to use an appropriate rate of axial distraction and dimension of the screw-PMMA construct, arriving at these after preliminary study. The rate of distraction was within the range of that used in previous studies (Cameron et al 1975; Schatzker, Sanderon and Murnaghan 1975; Frandsen et al 1984; Zindrick et al 1986; Daum et al 1988; Iversen et al 1988), and the use of five screw threads was the thickest possible mantle to lead reliably to failure at the screw-PMMA interface. Our results indicate that a surgeon using PMMA to enhance screw fixation should allow at least ten screw threads to interdigitate with PMMA to avoid any chance of failure at the screw-PMMA interface.

We have assumed that the best method of inserting a screw into PMMA is that which results in the greatest pull-out strength. In clinical situations, however, screws are subject to repetitive axial, bending and torsional loads. We were not able to study the endurance, bending or torsional strengths of the screw-PMMA constructs, but the relation of these to the pull-out strength is worthy of future study. We used pull-out strength to provide a reliable, repeatable and clinically relevant testing mode.

We found that the curing group was clearly the weakest, probably because the motion of the advancing screw generated small irregularities at the screw-PMMA interface. We therefore believe that screws should not be manipulated as the PMMA cures. Contrary to the conclusion of Cameron et al (1975), we found little difference between screws inserted into fluid or solid PMMA. This choice can be made by the surgeon, according to the circumstances and any preference; both methods provide firm and reproducible fixation.

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REFERENCES


