THE ELIMINATION OF SLIP BETWEEN PROSTHESIS AND FEMUR

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This paper describes tests to determine relative movement between a femoral head prosthesis and the bone of the femur produced by the application of steady axial compressive loads. Permanent relative movement between the two elements appeared to be due to the progressive failure under load of the interference fit* produced by the conventional method of insertion of the metal prosthesis into the neck of the femur. Further compressive tests were made after cementing the prosthesis into the femur and the results showed the virtual elimination of relative movement over the range of loads used.

In prosthetic replacement of the femoral head by the Moore, Thompson, or similar long-stemmed prostheses, the conventional method of achieving fixation by hammering the stem into the medullary canal of the femur relies upon an interference fit transmitting the load of body weight from metal to bone.

Loosening of the stem of the prosthesis is now widely recognised as one cause of defective clinical results of prosthetic replacement of the femoral head, and Charnley (1960) claimed a significant improvement when the prosthesis and the bone had been bonded by means of cold-curing acrylic cement.

![Diagram showing the test preparation.](image)

The following experiments were designed to test in vitro whether the load-bearing capacity of a prosthesis cemented into bone accorded with claims made from clinical observations. Preliminary tests had shown that, when a prosthesis was inserted into a cadaveric femur by the conventional method, even under comparatively small loads there was some permanent distal shift of the prosthesis inside the femur. It seemed that cementing the shaft of the prosthesis into the marrow space would provide a bearing area much greater than could be expected from a rather indeterminate interference fit.

* An interference fit is a tight fit between mating parts, a clearance fit a loose one.
Tests were made in the Mechanical Engineering Department at the Manchester College of Science and Technology to measure the effects of this modification.

**METHOD**

Four femora were used from subjects dying at ages from sixty-two to eighty-one years. The head of each femur was sawn off and a space was made in the marrow by a broach for the insertion of the metal prosthesis. The surgeon himself hammered the prosthesis into position using the amount of force that he would use on a living patient. A hole was cut in the side of the shaft of the femur to expose the end of the metal stem, so that a one ten-thousandth inch dial gauge clamped to the outside of the bone would register relative movement transmitted by a pivoted lever (Fig. 1).

The assembly was placed between the platens of a 5½ ton capacity Denison testing machine, the lower (sawn-off) end of the femur resting in a depression in a metal block. The load scale of the testing machine was adjusted to give full scale (360 degrees) deflection for a load of 0·55 ton.

After a small initial load to remove any slackness in the system, each specimen was tested in compression. Load increments of 0·01 ton (about 22½ pounds) were used, the dial gauge being read at each load up to approximately 0·20 ton (450 pounds) unless the dial gauge showed excessive relative movement before this load was reached. A few readings were taken during unloading to determine whether or not there was any "spring-back" in the system.

The tests were then repeated after each specimen had been modified by filling the marrow-space with cold-curing acrylic cement, pressing the prosthesis firmly into position and allowing ten minutes for the cement to set.

**RESULTS**

The results are shown in Figures 2, 4, 6 and 8, the plots for uncemented and cemented specimens being superimposed at the same scale, for comparison purposes. The enormous reduction in slip produced by using cement should be noticed. For completeness, a second plot using an enlarged scale has been given to show the variation of the (very small) slip with load for the cemented specimens (Figs. 3, 5, 7 and 9).

For all four specimens the permanent slip between the prosthesis and the femur produced by loads of up to 250 pounds was of the order of hundredths of an inch, rising to approximately one-tenth of an inch in two cases. The same specimens, when modified by cementing, gave permanent slip of the order of a few ten-thousandths of an inch, even when subjected to loads of up to 450 pounds.

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TABLE 1

**APPROXIMATE VALUES FOR SLIP PER 100 POUNDS LOAD**

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Age of cadaver</th>
<th>Slip per 100 pounds load (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Uncemented</td>
</tr>
<tr>
<td>1</td>
<td>62</td>
<td>0·025</td>
</tr>
<tr>
<td>2</td>
<td>68</td>
<td>0·035</td>
</tr>
<tr>
<td>3</td>
<td>75</td>
<td>0·020</td>
</tr>
<tr>
<td>4</td>
<td>81</td>
<td>0·100</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>0·045</td>
</tr>
</tbody>
</table>
Specimen 1. Subject aged 62 years.

Specimen 2. Subject aged 68 years.

Figs. 2 to 5
The relation of load to relative movement in two specimens, before and after cementing. Figures 2 and 4 show relative movement of both cemented and uncemented specimens throughout test. Figures 3 and 5 show, with enlarged movement scale, the variation of the slip in the cemented specimens.

Measurement of the average slopes of the load-deformation lines in Figures 2 to 9 gives the approximate values for the slip per 100 pounds load shown in Table I.

Sometimes the uncemented specimens would take up a particular amount of load and exhibit a steady value for slip, and then further slip would occur under a decreasing load (Figs. 6 and 8). This effect was to some extent apparent in all the uncemented specimens. It seems to indicate a gradual breakdown and readjustment of the interference fit between the prosthesis and femur. There was no sign of this effect in any of the cemented specimens.

In one specimen an axial split started in the calcar femoris and, accordingly, the loading was stopped—at about 150 pounds—to prevent further damage (Fig. 8). This specimen was,
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However, cemented in the usual way and under further test exhibited a resistance to slip equal to that of the other specimens.

Preliminary inspection of the uncemented specimens showed varying degrees of play between prosthesis and femur even before testing began. In Specimen 4 the prosthesis appeared to be very loose, those in Specimens 1 and 2 were slightly loose, while the prosthesis in Specimen 3 presented a good, tight fit. The last specimen originally exhibited more resistance to loads of up to about 250 pounds than did the others. This suggests that the performance of the normally constructed interference fit may be somewhat indeterminate and certainly not related to the age of the subject from which the bone specimen was obtained.
SUMMARY

1. The customary method of broaching and of knocking the prosthesis down into the neck of the femur produces an indeterminate interference fit.
2. The usual interference fit may suffer progressive breakdown under even small, steady loads. This results in a permanent relative movement between prosthesis and femur as the metal insert "beds" into the bone.
3. Modification of the usual practice by providing a clearance fit between prosthesis and femur and cementing of the metal into the bone provides a system which has been shown to be free of breakdown under steady loads up to about 450 pounds.
4. By cementing the prosthesis shaft into the femur permanent relative movement between the elements has been shown to be reduced from approximately four-hundredths of an inch per 100 pounds load to two ten-thousandths of an inch per 100 pounds load—that is, a reduction of 200 to 1.

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REFERENCE