INTRODUCTION

Osteolysis at the bone/cement interface is the principle cause of long-term failure of cemented hip arthroplasty. Raised cyclical fluid pressure induces osteolysis in animal models of aseptic loosening, but there are no proven mechanisms by which this pressure can be generated within an artificial joint. Raised fluid pressure is generated in failed total hip joints but it is not known whether this is a cause or an effect. RSA analysis of well fixed cemented femoral stems has measured step-to-step, asymptomatic, recoverable, micromotion. The femoral stem pump theory links this movement to periprosthetic osteolysis, proposing stem movement within its mantle generates cyclical fluid pressure at the stem/cement interface which is transmitted to bone either at the margins of the bone/cement interface or via defects in the mantle. Matt stem surface finish had an adverse effect on the Exeter implant survival, explanatory mechanisms have been proposed; stem surface finish influences fluid flow at the interface and rough stem movement within the cement mantle causes abrasive wear and possibly stem destabilization.

The study aim was to develop a physiological, mechanical analogue of a cemented femoral stem to investigate the femoral pump. The hypotheses were: inducible stem micromotion causes cyclical pressure generation at the stem/cement interface and that this process is influenced by stem surface finish and mantle conformity to the stem.

METHODS

The experimental apparatus or Hip Arthroplasty Pressure Simulator (HAPS) consisted of a testing chamber, housing the model femoral stem and cement mantle, mounted on a materials testing machine or MTM. Vegetable oil was used as an artificial synovial fluid. The filler tank, suspended above the HAPS, dictated the resting fluid pressure. The chamber was held at body temperature by an integral water jacket in the outer wall.

Five pressure transducers on the exterior of the casing communicated with the stem/cement interface via tappings in the mantle at the postero-medial & antero-lateral aspects of the proximal mantle, the posterior & anterior surfaces of the mid-stem and the implant tip.

The stem was loaded via the HAPS lid; a silicone gaiter sealed the gap between the lid and the neck of the casing. The axial hydraulic actuator applied force in compression at the true, scaled, medial offset of the stem. The horizontally mounted pneumatic actuator applied torque in both internal and external rotation. The pneumatic actuator activity was coordinated to that of the load controlled axial actuator.

The scaled, half-sized, model stems were based an Exeter size 1, 37.5 mm offset stem. The proximal stem was redesigned to facilitate its coupling to the lid. The stems were either polished, 0.03μm Ra, or rough finish, 2.2μm Ra. The cement mantle was created using six mixes of chilled cement poured into the testing chamber at two minutes. The polished stem, preheated to 60°C, was inserted at 12 minutes with a chilled cement poured into the testing chamber at two minutes. The used to create all mantles as it caused least damage to the cement surface. The stem was removed and the 5 mm offset stem. The proximal stem was redesigned to facilitate its coupling to the lid. The stems were either polished, 0.03μm Ra, or rough finish, 2.2μm Ra. The cement mantle was created using six mixes of chilled cement poured into the testing chamber at two minutes. The polished stem, preheated to 60°C, was inserted at 12 minutes with a chilled cement poured into the testing chamber at two minutes. The used to create all mantles as it caused least damage to the cement surface. The cement mantle causes abrasive wear and possibly stem destabilization.

The study had two experimental groups; polished and rough, with two stems in each group. The stems were cyclically loaded 1.5 million times in 100000 cycle trials at 2 Hz, punctuated by 4 hour stress relaxation periods for the cement. Pressures were sampled at the start and at 1 and 1.5 million cycles.

The interface pressures are expressed as the clinically relevant parameters of median maximum range of pressure and the median peak pressure per cycle. Data distribution was assessed using histograms of individual trial data and the Lilliefors test for normality. The Wilcoxon sign rank test was used to compare data groups, α=0.05.

RESULTS

The pressure data were not normally distributed. The measurement precision was reflected in the inter-quartile range, IQR for the median pressure over 90 cycles for each pressure transducer output per mantle. The IQRs varied between 0.03-3.83 mmHg over the 4 mantles. This suggests, at worst, a measurement precision of ± 2 mmHg. Measurement precision was not affected by stem surface finish type, p=1.

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<tr>
<th></th>
<th>ROUGH</th>
<th>POLISHED</th>
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<tr>
<td>TIP</td>
<td>START Median Pressure range mmHg</td>
<td>1.5 MILLION Median Pressure range mmHg</td>
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<tr>
<td>PROX ANTLAT</td>
<td>21-28</td>
<td>16-31</td>
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<tr>
<td>ANT MID-STEM</td>
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<td>PROX POSTMED</td>
<td>23-28</td>
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<tr>
<td>POST MID-STEM</td>
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Interface pressure fluctuations were universally found secondary to stem micromotion under load with the ranges stretching both positive and negative to resting values. Both the median maximum pressure and pressure range increased markedly with the rough stems after 1.5 million cycles, with up to 100 times increase in the median pressure range observed. Conversely the polished stems did not generate significantly greater pressures after 1.5 million cycles. The range of torsional micromotion varied between the 2 stem types; the arc of movement of the polished stems did not increase remaining 1.6°, whereas the arc for the rough increased from 1.1° to 2.8° over 1.5 million cycles.

DISCUSSION

The two stem types behaved very differently. The pressures developed by both groups at the start did not vary greatly. The rough stem exhibited greater torsional micromotion at 1.5 million cycles with corresponding dramatic increase in maximum interface pressures and ranges. Cyclic pressures of less than this magnitude have induced osteolysis in animal models. The polished stems, in contrast, exhibited no changed torsional micromotion and no increase in pressure. The study is limited by the low number of stems studied and the load control systems employed which allowed close but not exact replication of physiological loading schedules.

SUMMARY

Cyclic, physiological loading of rough stems leads to asymmetric mantle wear and 1 to 2 degrees of stem rotational instability. This does not occur with polished stems. Stem micromovement within asymmetrically worn mantles induces high cyclical fluid pressures at the stem/cement interface. This is probably a potent cause of osteolysis and implant aseptic loosening.