Reduction of the potential for thermal damage during hip resurfacing

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Resurfacing arthroplasty of the hip has recently seen a resurgence of interest with the advent of third-generation metal-on-metal devices. These are being implanted in increasing numbers, especially in young and active patients.1,2 Most available devices use hybrid fixation with an uncemented acetabular component and a cemented femoral implant.1,2

In conventional total hip replacement (THR), thermal damage due to polymerisation of bone cement can result in necrosis of bone.3,4 Finite-element5,6 and experimental studies7 have supported these findings. Typically, the temperature of polymerising cement is between 50˚C and 55˚C in a total hip replacement (THR).5,8 With a replacement arthroplasty, relatively large cysts in the femoral head are often filled with cement, potentially giving rise to even higher temperatures.

Studies of the cement-bone interface surrounding total hip prostheses retrieved at post-mortem after short-term implantation have shown bone and marrow necrosis extending for several millimetres from the cement.5,8 It has been suggested that the fibrous tissue membrane which often forms when the necrotic bone is removed may allow micromovement, instability and loosening of components.9 The deleterious effects of bone cement have been shown to occur in the cancellous bone of resurfaced femoral heads at long-term retrieval,10 although such studies have also demonstrated that healing of initial interfacial bone necrosis does occur.11 A unique complication of resurfacing arthroplasty is fracture of the femoral neck with a reported incidence between 1% and 4%.12,13 While the cause of a fracture is probably multifactorial, weakening of the bone due to creeping substitution of necrotic bone may be contributory.12

We have investigated the thermal effects caused by the polymerisation of bone cement during resurfacing and have assessed the effects of modifying the surgical technique to include intra-osseous suction at the level of the lesser trochanter, extensive pulsed lavage and early reduction of the joint.

Patients and Methods

After approval of the study protocol by the Institutional Ethics Committee, patients undergoing either a standard THR or a resurfacing procedure for osteoarthritis were recruited. The THR group (manual lavage) comprised two men and two women with a mean age of 68 years (57 to 74), with primary osteoarthritis as the indication for treatment. Before excision of the femoral head and completion of a standard THR, the head was resurfaced and temperature measurements were obtained. The resurfacing group (pulsed lavage and modified...
surgical technique), had five patients, two women and three men, with a mean age of 52 years (20 to 63) and a diagnosis of osteoarthritis in four and post-traumatic arthritis after an acetabular fracture in one.

During the definitive resurfacing operation the temperature of the femoral bone was measured. All patients received a Conserve Plus resurfacing implant (Wright Medical Technology, Arlington, Tennessee), with one surgeon (KADS) performing all the operations.

For both groups, before cementing, two sterile thermocouple probes (Type T; Kalestead Limited, Braintree, United Kingdom) were inserted into the femoral head through tunnels drilled from the lateral aspect of the femur using a 2 mm diameter Kirschner wire (Fig. 1). Positioning involved placement of the tips of the probes within 1 mm of the final cement layer. This was confirmed by intra-operative radiographs taken under full aseptic conditions. The insertion of the probes and radiological confirmation of their position added approximately 15 to 20 minutes to the duration of the operation.

In the THR group, during the preparation of the dummy resurfacing, only manual lavage applied by a finger-pressurised syringe was used. The femur was prepared for resurfacing in the standard manner. In both groups the recommendations of the European instrumentation of the Conserve Plus system were followed to obtain a cement mantle 0.5 mm thick. The dummy femoral component was cemented in place and the hip remained dislocated while the cement polymerised. Osteotomy of the femoral neck was then performed and the resurfaced head removed with the thermocouples still in place. Conventional THR was completed. The excised femoral head was sectioned transversely to determine the locations of the tips of the probes. The amount of bone remaining which had not been penetrated by cement was measured as a percentage of the cross-sectional area.

In the resurfacing group, the usual surgical technique of the operating surgeon (KADS) was used, with preparation of the acetabulum and insertion of an uncemented component performed first. A specially-designed suction cannula with an internal diameter of 3 mm was inserted into a hole drilled in the lesser trochanter and suction was applied. The cannula was designed to penetrate the centre of the intramedullary canal for a distance of 30 mm (Fig. 1). The remainder of the femoral preparation was carried out with this cannula in place. Before cementing the femoral component, pulsed lavage was applied to the prepared femoral head for 45 seconds using sterile saline at the ambient temperature of the operating theatre, between 17°C and 20°C. The bone was then dried using suction applied to the dome of the head and the femoral component was cemented in place. One minute after cementing, pulsed lavage was applied to the component for a further two minutes. The suction cannula in the lesser trochanter was removed and the hip was then reduced. Ten minutes after commencing mixing the cement, pulsed lavage was applied...
to the reduced joint for a further two minutes. The thermocouple probes were removed after collection of the data had been completed and the incision was closed.

In every case Simplex cement (Stryker, Newbury, United Kingdom) was hand mixed in an open bowl for one minute before being poured into the inverted femoral component to the level of the top groove within the implant. This equated to half the internal volume of the prosthesis. The femoral components were implanted 2.5 minutes after starting preparation of the cement.

The temperature probes were connected to a temperature recorder (TCH01; Pico Technology Limited, Cambridge, United Kingdom) controlled by a personal computer. Two additional wire thermocouples (Type K; Kalestead Limited), one for recording the room temperature and one for placing into the cement remaining in the mixing bowl, were also connected to the temperature recorder. Data were recorded at 2Hz, with capture of the data initiated once the probes were in place and terminated when the cement had cured. PicoLog software (Pico Technology Ltd, Cambridge, United Kingdom) was used to record the data.

Statistical analysis. The measured data were further processed using customised Matlab version 6.5 software (The MathWorks Corporation, Natick, Massachusetts). The maximum recorded temperature in the femur was extracted for each patient and the differences between the two groups were analysed using the Mann-Whitney U test with SPSS v12 software (SPSS Inc., Chicago, Illinois). Statistical significance was defined as a p-value ≤ 0.05.

Results

The thermal behaviour of the cement remaining in the mixing bowl was similar in every case, with the temperature increasing rapidly during polymerisation (Figs 2 and 3) to reach a median maximum of 91.4°C (88.7°C to 101.2°C). The cement then began to cool slowly (Fig. 2). For the THR group, the recorded femoral temperature started to increase before that of the cement remaining in the mixing bowl, with a median maximum temperature of 47.2°C (37.0°C to 67.9°C; Table I). The femoral temperature profiles for the resurfacing group were different from those of the THR group. Suction on the lesser trochanter caused the femoral temperature to drop initially (Fig. 3) from a median of approximately 30°C (29°C to 35°C) to that of 20°C (17°C to 22°C) to rise again slightly before cementing. The application of pulsed lavage also reduced the femoral temperature by an additional 4°C before cementing. The maximum recorded temperatures were significantly lower for the resurfacing group with a median value of 32.7°C (31.7°C to 35.6°C) (p = 0.014) (Table I).

Sectioning the excised dummy resurfacing heads from the THR group confirmed that the tips of the thermocouples were positioned between 0.5 mm and 1 mm from the cement layer (Fig. 4). There was considerable variation in the amount of bone measured in the cross-sections of the dummy resurfaced heads into which cement had not penetrated, ranging between 18.3% and 63.8% (Table I). The percentage of unpenetrated bone had a negative correlation with the maximum recorded temperature in each example, but this did not reach statistical significance (p = 0.15). There were no complications arising from the measurement procedure in either group.

Discussion

The principal limitation of our study was the small number of patients in each group. Originally it had been planned to
recruit ten subjects for each, but recruitment was stopped when the data showed a highly significant difference between the groups. There was also a difference between the mean ages of the groups, with the resurfaced group being younger. We felt that this was unlikely to have influenced the maximum temperatures recorded but acknowledge that it may have been a source of bias.

The thermal effects of the curing process of bone cement have been well documented in terms of bone necrosis, arterial damage and cardiopulmonary complications. In a resurfacing arthroplasty the long-term survival of the implanted hip is dependent upon viable femoral bone and stable interfaces. The complication of fracture of the femoral neck may be associated with osteonecrosis. Retrieval analysis of failed hip resurfacing arthroplasties produced by Midland Medical Technologies has shown that the penetration of cement was often extensive and over-penetration was significantly associated with failure due to femoral loosening. A finite-element model of hip resurfacing arthroplasty using a moderate amount of penetration of cement and a cement-filled cyst has predicted that the temperature was sufficiently elevated for a sufficient time to cause necrosis at the cement-bone interface. The data from our study demonstrate that high bone temperatures which could produce necrosis of bone cells can occur during hip resurfacing. When modification of the surgical technique was performed with the use of suction at the lesser trochanter, generous use of pulsed lavage and reduction of the femoral component before completion of polymerisation of the cement, significantly reduced temperatures were recorded, with the maximum temperatures below the threshold required to cause thermal damage. It is interesting to note that there was markedly less variation in the maximum recorded femoral temperature in the resurfacing group (variation 3.9°C) compared with the THR group (variation 30.9°C). There are probably a number of factors which influenced the dissipation of heat. The maximum temperatures in the THR group appeared to correlate with the amount of penetration of cement, but this was not statistically significant, probably because of the small number of patients. We are unable to comment on the extent of the penetration of cement in the resurfacing group, but it might reasonably be anticipated that the presence of the suction would have enhanced cement interdigitation. Nevertheless, the modified technique appeared to limit the elevation of temperature with repeatable dissipation of heat.

Suction reduced the femoral temperature by approximately 10°C during the first five minutes of application. The cannula used in our study was designed to reach the centre of the intramedullary canal of the femur, and had a relatively large diameter of 3 mm. Those of smaller diameter and shorter lengths may not be as effective. The combination of reduction of the femoral component before the completion of polymerisation and lavage is probably the most important aspect of the modified technique. When the joint is reduced, the femoral component is in contact with the acetabular component and the whole implanted joint sits in a pool of lavage fluid. This provides a large thermal sink, removing heat from the femoral cement-bone interface. The thermal-sink effect could be further enhanced by using cooled lavage fluid, as has been previously suggested for cranial surgery. Early reduction is only possible for hip resurfacing systems with thin cement mantles and requires that the acetabular component be implanted first. The available hip resurfacing systems require cement mantles ranging from 0 mm to approximately 2 mm in thickness. The femoral components for those systems with thin cement mantles are usually stable immediately after impaction onto the femur, before curing of the cement. Such

<table>
<thead>
<tr>
<th>Maximum temperature (°C)</th>
<th>Unpenetrated bone (%)</th>
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<tr>
<td>THR group</td>
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<tr>
<td>67.9</td>
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</tr>
<tr>
<td>31.7</td>
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</tr>
<tr>
<td>35.6</td>
<td>-</td>
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*- not applicable

Table I. Maximum recorded temperatures during hip resurfacing arthroplasty for the total hip replacement (THR) group (n = 4; manual lavage) and the resurfacing arthroplasty group (n = 5; modified technique with pulsed lavage, trochanteric suction and early reduction).
devices can be immediately reduced without risk of displacement. This is not possible when a thicker cement mantle is used since the femoral component is unlikely to be secure until the cement has cured. It is also probable that a thicker cement mantle will generate higher femoral temperatures since the thickness of the cement is directly related to the maximum temperature generated.\(^{18}\) We recognise that in the THR group the hip remained in the dislocated position throughout the temperature monitoring. While this may have restricted the blood flow through the femoral head which could have aided dissipation of heat, we felt that the more important contribution afforded by reduction is the heat sink provided by the acetabular component.

In summary, the maximum recorded femoral temperature during cemented hip resurfacing in our study was approximately 68°C. A modified surgical technique using suction on the lesser trochanter, generous pulsed lavage and early joint reduction lowered this significantly to a maximum of approximately 36°C, which is less than the temperature reported to cause bone cell necrosis. We recommend this modified technique since the potential for thermal bone necrosis is significantly reduced.

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References