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# THERMAL EFFECTS OF CEMENT MANTLE THICKNESS FOR HIP RESURFACING

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# Abstract

Hybrid hip resurfacing arthroplasty (HRA), with uncemented acetabular and cemented femoral fixation is increasingly popular as an alternative to total hip replacement. There is concern about femoral neck fractures and long term survival has not yet been demonstrated. Thermal necrosis may be an important factor for neck fracture and will affect the viability of the femoral bone. This cadaveric study investigated the thermal effect of thick (1.5mm, n=3) and thin (0.5mm, n=3) cement mantles; five thermocouples were used to record temperature at the femoral bone/cement interface during HRA. The maximum recorded temperatures were significantly higher when a thick cement mantle is used (45.4ºC), compared to a thin cement mantle (32.7ºC). In order to reduce the potential for thermal necrosis, the thin cement mantle technique is recommended.

# Introduction

The latest generation of metal-on-metal hip resurfacing arthroplasty (HRA) devices have led to a resurgence of interest in resurfacing as an alternative to total hip replacement (THR), especially for young and active patients [1,2]. There are a number of designs available from all the major manufacturers', almost all using hybrid fixation, with press-fit acetabular fixation and cemented femoral fixation.

The various HRA devices differ in terms of component design. These differences are marketed as advantages despite little independent outcome data to support such claims. In terms of cementing technique for the femoral component there are two main philosophies, which can be simplified to either thick or thin cement mantle. The ASR (DePuy, Leeds, UK) has a thick mantle philosophy; the Conserve Plus (Wright Medical Technology, Arlington, TN, USA) can be used with either a thick or thin mantle depending on surgical preference, the Birmingham Hip (Smith and Nephew, Memphis, USA) and the Cormet (Corin, Cirencester, UK) have thin mantles. The designs leave either a one to two millimetre gap between the exterior surface of the reamed femoral bone and the interior surface of the femoral component, producing a thick mantle; or a virtually zero to 0.5mm gap, giving a thin cement mantle. The thick mantle designs require cement that is applied to the prepared head when it has a doughy consistency. The femoral component is then applied. The femoral component only becomes secure once the cement cures, and then the hip can be reduced. The thin mantle designs require a liquid consistency cement to be poured into the femoral component, filling the interior to a given level and then applying the head to the femur while the cement is still liquid. The femoral components of thin mantle designs are a tight fit to the reamed femur; thus the hip can be reduced once the excess cement is cleared away.

There is concern about the viability of the femoral head and neck after HRA. Thermal damage due to cement curing has been linked to radiolucency and prosthesis loosening [3,4]. Dead bone near the prosthesis/bone interface may result in implant loosening; more extensive necrosis in the femoral head may lead to late failure from collapse of the head. A unique complication of HRA is neck fracture, incidences up to four percent are reported [5,6]. Fracture is multi-factorial, however the weakening due to creeping substitution of necrotic bone is probably an important factor [5].

The volume of cement is related to maximum temperature occurring during curing [7]. This study set out to compare the thermal effects at the bone/cement interface of cement mantle thickness, comparing the thick mantle technique to the thin mantle technique.

## Materials and Methods

Six fresh frozen cadaveric femora were obtained. The femora were supplied stripped of soft tissues, and were thawed prior to experimentation. Each femur was prepared to receive a size 52 (outer diameter 52mm) femoral component of the Conserve Plus hip resurfacing system. The Conserve Plus was chosen, as it can be used with both thick and thin cement mantles. In all cases unfinished size 52 Conserve Plus femoral components were used. The components were obtained from the manufacturer prior to the final finishing of the exterior surface; the interior surfaces were fully finished. The femora were randomly selected for thick (n=3) or thin (n=3) cement mantle, with the gap between the reamed bone and component inner surface being 1.5mm and 0.5mm respectively. No lavage was used during the specimen preparation.

Each femur then had five thermocouple probes implanted such that the measuring tips were arranged as shown in Figure 1. Three of the thermocouples, at locations F1 to F3, were Type K wire thermocouples (Kalestead Ltd, Braintree, Essex, UK), and placed through holes drilled with a 2mm k-wire. The wire thermocouples were inserted from the neck with the tips protruding from the reamed surface; the wires were then bent such that the measuring tips lay flat against the reamed bone. The remaining two thermocouples (F4 and F5) were Type T needle thermocouples (Kalestead Ltd, Braintree, Essex, UK), placed through holes drilled again with a 2mm k-wire, such that tips were just below the reamed bone surface.

The thermocouples were connected to a PC controlled temperature logger (TCH01, Pico Technology Limited, Cambridge, UK). Two additional Type K thermocouples, one for recording the room temperature and one for placing into the cement remaining in the mixing bowl, were also connected to the temperature logger. Data were recorded at 2 Hz using PicoLog software (Pico Technology Limited, Cambridge, UK), with data capture initiated once cement mixing began and terminated after 25 minutes.

For each femur, one mix of Simplex cement (Stryker, Newbury, UK), kept chilled at 4ºC prior to use, was mixed in an open bowl for one minute. For the thick mantle technique, cement was applied to the reamed femoral surfaces at four minutes after mixing began; at this stage the cement had become doughy. The femoral component was then placed on the femur, with care taken to ensure that the component was fully seated and all excess cement trimmed away.

For the thin mantle technique, the cement was poured immediately after mixing into the inverted femoral component, filling it to the top groove within the component. This level of filling equated to half of the internal volume of the prosthesis. The component was applied to the femur at two and half minutes after the start of mixing, and again care was taken to ensure full seating and excess cement removal. The experimental arrangement dictated that the femoral component was introduced from the direction of thermocouple F2 (Figure 1); this arrangement was designed to mimic the position of the femur on the operating table during HRA surgery.

The implanted femurs were left undisturbed during the remainder of the data capture period. The recorded data were exported in comma separated variable format from the PicoLog software, and further processed, using a custom routine, with Matlab (version 6.4, The MathWorks, MA, USA). The maximum recorded temperature values from each thermocouple were obtained for each femur. The data for all thick and thin cement mantles were compared using box and whisker plots and the Mann-Whitney U non-parameteric statistical test. All statistical processing was performed with SPSS (version 12, SPSS, IL, USA).

## Results

The typical temperature profile for the cement remaining in the mixing bowl showed a rapid increase in temperature at approximately 15 minutes after the start of mixing, reaching maximum temperature at approximately 17 minutes (Figure 2). The maximum cement temperatures ranged from 78.6 to 98.4ºC (Figure 3). The cement then began to cool relatively slowly. The thermocouples in the femur recorded slower increases in temperature and the maximums were lower than those for the cement. All femurs were at room temperature at the start of each measurement (approximately 20ºC). Room temperature remained constant during the experiment for all six femurs (Figures 2 and 3). For the femoral thermocouples, location F2 (Figure 1) had the highest median value for maximum recorded temperature for both cement techniques (Figure 3). The thick mantle technique consistently gave rise to higher maximum recorded temperatures for every thermocouple location in the femur. The overall median values of the maximums for the recorded femur temperatures were 45.4ºC (range 41.6ºC to 56.5ºC) for the thick mantles and 32.7ºC (range 26.6ºC to 39.3ºC) for the thin mantles (Figure 4); this difference was statistically significant (p=0.05).

# Discussion

The majority of hip resurfacing femoral components use cemented fixation. For good fixation and long term survival of the implanted hip, viable femoral bone is required. This bone should be capable of transmitting loads from the implant to the rest of the femur. Dead bone in the femoral head may lead to implant loosening or late failure due to collapse. Neck fracture after HRA is multi-factorial in etiology; undoubtedly extensive necrosis will contribute to weakening the implanted femur. These issues lead to concerns about necrosis, and it is well documented that self curing bone cement is associated with thermal necrosis [3,8,9]. This study set out to examine the thermal effects of cement curing, in particular the influence of cement mantle thickness, for HRA surgery.

There was a significant difference between the thick and thin cement mantles in terms of the maximum recorded temperatures at the cement/bone interface. The thick cement mantle technique gave rise to higher maximum values, approximately 45ºC compared to approximately 33ºC for the thin mantle technique. These values represent a 25ºC rise from the ambient femur temperature for the thick mantle technique compared to a 13ºC rise for the thin mantle technique. This result is not unexpected, similar effects have been reported for total hip and tumour surgery [9,10].

It was interesting to note that in all cases location F2 had the highest temperatures recorded. This location was nearest to distal edge of the prosthesis as it was placed on the femur, the cement mantle will be thickest here for both techniques. For the thick mantle, the cement placed on the femur will flow distally, and for the thin mantle technique, the cement in the component will gather distally as the component is placed on the femur.

A limitation of this study is the use of cadaveric specimens. Obviously these will have thermal properties which are very different from the *in vivo* situation. However, there are advantages in using such specimens, the major one being that a relatively large number of measurements can be made at the main zone of interest, the cement/bone interface. In addition, with cadaveric specimens the repeatability of determining the measurement locations is higher than is possible *in vivo*. As this study was designed to compare the thermal effects of cement mantle thickness, the relative differences in temperature is of primary interest, not the absolute values; all other factors which could reasonably be expected to influence recorded temperature were kept constant. It is expected that the absolute maximum *in vivo* temperatures will be higher, as the starting temperatures will be higher (this has been confirmed by an *in vivo* pilot study).

Another limitation of this study was the small number of specimens used, this was limited by availability.  Despite the small number of specimens, statistically significant effects were observed.

If the same rises above ambient can be extrapolated to the *in vivo* condition, assuming that ambient femur temperature is approximately 30ºC (from *in vivo* pilot data), then maximum temperatures of 55ºC for the thick mantle technique could be expected and 43ºC for the thin mantle technique.  The critical temperature for bone necrosis is approximately 47ºC [11], so it would be expected that the thick mantle technique will give rise to more thermal necrosis.  Mjoberg *et al* [4,9] reported that thermal necrosis gives rise to radiolucent lines appearing during the first two years after implantation and hypothesised that heat injury could be a risk factor for loosening of total hip components.  This effect may be more severe for a hip resurfacing device; extensive thermal damage to the bone in the remaining femoral head could give rise to a whole layer of bone undergoing creeping substitution, dramatically reducing the load transmitting properties.  During HRA surgery, key holes are often drilled into the head, and any cysts present are curetted and filled with cement.  These procedures will increase the amount of cement present and therefore give rise to higher temperatures.

With the thin cement mantle technique it is possible to reduce the joint prior to the curing of the cement.  The femoral component will then be in contact with the acetabular component, and will be in a fluid pool.  This will provide a larger thermal sink, thus reducing the maximum temperatures resulting from cement curing.  This is not possible for the thick mantle technique, the femoral component is not secure until after curing.  The benefits of the thin mantle technique's thermal profile have to be balanced with the risks of damage due to high impaction forces.  For some thin mantle designs, with very small clearances (less than 0.3 mm), the femoral component has to be impacted onto the femur.  This can give rise to fractures in the femoral head and neck, if the impaction is performed with excessive vigour.

## Conclusions

The maximum recorded temperatures at the bone/cement interface during HRA surgery are significantly higher when a thick cement mantle is used, compared to a thin cement mantle.  In order to reduce the potential for thermal necrosis, the thin cement mantle technique is recommended.

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**Figure Captions:**

Figure 1: Position of thermocouples on reamed femoral head, looking directly onto the reamed head. Locations F1 to F3 were where Type K wire thermocouples were placed, locations F4 and F5 were for the Type T needle thermocouples.

Figure 2: Typical data from the thermocouples placed in the femur, and those used to measure room temperature and that of the cement remaining in the mixing bowl. Zero time equates to the start of cement mixing.

Figure 3: Box and whisker plot showing the maximum recorded temperatures for each thermocouple location.

Figure 4: Box and whisker plot showing the overall maximum recorded temperatures in the femur for both the thick and thin cement mantle techniques.

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