Cement interface temperature in hip arthroplasty

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The temperature was measured using thermocouples in the bone-cement interface during cement curing in 30 total hip replacement operations. A modern technique was used, including lavage and precooled vacuum-mixed cement. The mean maximum temperature in the acetabulum was 43 (38–52) °C and in the femur 40 (29–56) °C. The use of a precooled femoral prosthesis did not affect the peak temperature.

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Thermal injury of bone induced by cement might be one cause of aseptic loosening (Charnley and Crawford 1968, Willert et al. 1974, Feith 1975, Huiskes 1980, Mjöberg et al. 1984). Polymerization of bone cement is an exothermic reaction resulting in elevated interface temperatures, which in different reports varies between 37 and 122 °C (Homsy et al. 1972, Biehl et al. 1974, Jefferiss et al. 1975, Seidel et al. 1977, Huiskes 1980, Toksvig-Larsen and Ryd 1989). Eriksson (1984) found the threshold temperature for impaired bone regeneration to be in the range of 44–47 °C for 1 minute of exposure.

We investigated the temperature in the in vivo bone-cement interface during hip arthroplasty using a modern cementation technique, including lavage of the bone bed and pressurization of precooled, vacuum-mixed bone cement.

Patients and methods

Thirty total hip replacements were included in the series. Ten patients had rheumatoid arthritis, 8 had arthrosis, 5 were operated on for a failed osteosynthesis of a femoral neck fracture, and 7 were operated on with a revision of a mechanically loosened, primarily cemented total hips. In 7 of the 10 patients with rheumatoid arthritis, precooled (4 °C) femoral prostheses were used. In all the patients, a polyethylene acetabular component without metal backing and a chrome-cobolt femoral component, Scan hip® (MITAB, Sweden), were used. Precooled (4 °C) cement (Refobacin Palacos®, Palacos with gentamicin, Schering Corporation, Chicago) was used; and after lavage of the bone bed, vacuum-mixed cement (Lidgren et al. 1987) was applied using a pressurization technique (Halawa et al. 1978, Miller et al. 1979, Ling 1986, Lidgren 1988). The amount of cement was calculated as the mean thickness of the cement between the bone and the prosthetic component, measured on the postoperative radiographs in both AP and lateral views at the level where the thermocouples were inserted.

The temperature measurements were performed with thermocouples type copper-constantan—

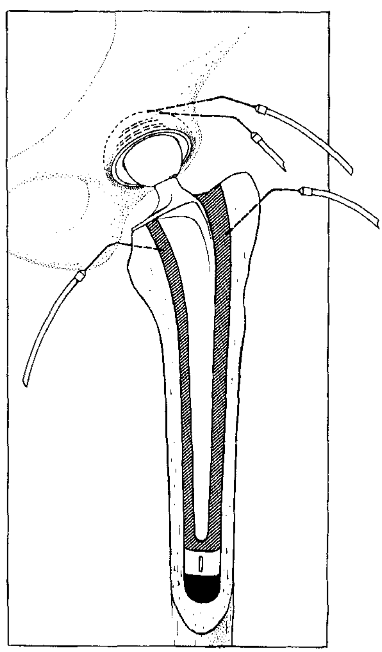

Figure 1. Insertion of the thermocouples.

Table 1. Recorded temperatures. Mean, *SD*, and range

	n	Temperature (°C)		
Acetabulum	30	43	*3*	38–52
Femur	41	40	*6*	29–56
Femur precooled stem	13	40	*5*	34–48
Acetabulum, revision	8	45	*3*	40–48
Femur, revision	5	39	*2*	36–44

Table 2. Number and duration (sec) of recordings above 44 and 47 °C

	> 44 °C		> 47 °C	
	n	Time range	n	Time range
Acetabulum	5/30	50–290	2/30	60–180
Femur	4/41	170–420	4/41	80–140
Femur, precooled	2/13	170–300	1/13	80

Exacon CN 7 (Exacon Scientific Instruments Aps, Roskilde, Denmark) connected to a pen recorder—BBC SE 460 (Brown Boveri Goerz Metrawatt, Vienna, Austria), temperature range 0–100 °C (total accuracy ± 1 °C).

The thermocouples were placed so that their tips came to lay flush with the prepared bone surface, i.e., in the bone-cement interface. In the acetabulum the points of measurement were at the middle of the circumference of the prepared bone bed. In the femur the points of measurements were in the trochanteric region (Figure 1).

Totally, 30 measurement points were recorded during the curing of the cement in the acetabulum, and 41 measurement points were recorded during the curing process in the femur after exclusion of four acetabular measurements and four femoral measurement, because the thermocouples had been displaced during the curing process. The maximum temperatures were recorded, and the time the temperatures were above 44 °C and 47 °C was estimated.

Results

The mean maximum cement-curing temperature in the acetabulum was 43 °C and in the femur 40 °C. Using precooled femoral prostheses, the mean maximum temperature in the femur was 40 °C (Table 1).

In the acetabulum, 5/28 temperature recordings were above 44 °C, and two of these were above 47 °C. In the femur, 4/41 recordings were above 44 °C—all of them above 47 °C. The longest duration above 44 °C was 7 minutes and above 47 °C 2 minutes and 20 seconds (Table 2).

The setting time was prolonged about 2 minutes using the precooled femoral component.

The amount of cement in the regions corresponding to the measurements was 4.4 (2–15) mm in the acetabulum and 4.6 (1–11) mm in the femur.

The ambient bone temperature was 32 ± 2 (27–35) °C in the acetabulum and 29 ± 3 (22–35) °C in the femur.

Discussion

The rate of setting, the size and shape of the mass, and the thermal properties of the surrounding material—including bone, blood, and the plastic and metallic components of the prosthesis—all influence the rate of buildup and dissipation of the relatively fixed amount of heat and determine the actual temperature of the setting mass. In trying to reduce the temperature at the bone-cement interface, one must first realize that the maximum temperature is a function of the total amount of heat produced by the cement, the rate at which heat is produced, the effective thermal conductivity and heat capacity of the bone, prosthesis and cement, and the initial conditions of the prosthesis-cement-bone system.

Eriksson (1984) found the threshold temperature for impaired bone regeneration to be in the range 44–47 °C when measured at a distance of 0. 5 mm and applied for 1 minute.

In this study, nine out of the 69 temperature recordings in 30 patients who had been operated on with a total hip replacement were above 44 °C with a maximum exposure time of 4 minutes and 50 seconds when using a modem cementation technique. Pressurization should theoretically raise the interface temperature a little, because the cement penetrates about 2 mm into the bone, which would draw the recording points toward the cement side. We found a slightly higher temperature at the acetabulum as compared with the femur. This could be explained by a heat-sink phenomenon (Huiskes 1980) and the fact that the precementation temperature was slightly higher in the acetabulum. On the other hand, we did not find that there was any benefit from using precooled femoral components.

In the literature, there is an extensive documentation of the exothermic reaction of bone cement, but all of them have been done with a different set-up—both in vivo and in vitro. In the in vivo studies, the bone-cement interface temperatures have ranged from 37 to 70 °C (Homsy et al. 1972, Meyer et al. 1973, Biehl et al. 1974, Labitzke and Paulus 1974, Jefferiss et al. 1975, Seidel et al. 1977, Toksvig-Larsen and Ryd 1989), whereas in vitro studies far higher temperatures have been documented—the maximum temperature having been 122 °C in the center of a 52-g Palacos ball (Ohnsorge and Goebel 1969, Ohnsorge and Kroesen 1969, Hupfauer and Ulatowski 1972, Meyer et al. 1973, Holm 1980, Lidgren et al. 1987). One explanation of this wide temperature range is given by Haas et al. (1975), who found a difference of 9 °C in the peak temperature when analyzing 10 batches of bone cement. The results could not be related to the experimental conditions.

Finite element methods support the results of our investigation and our concluding that the maximum bone temperatures would not be higher than 60 °C (Huiskes 1980, Swenson et al. 1981).

The position of the thermocouples is a critical factor in temperature recording at the interface as shown by our eight recordings where the probes slid into the cement. High temperatures were recorded in these cases, 71–79 °C, well in agreement with Holm (1980).

Attempts to lower the bone temperature using precooled femoral components were of no benefit in our investigation. This accorded with Meyer et al. (1973), but Biehl et al. (1974) found a 4 to 5 °C lower temperature in the bone-cement interface when using a precooled prosthesis. The heat-sink capacity of the implant, reducing the initial temperature by 10 °C, will have the same effect as increasing the stem radius by 1 mm for a radius of 6 mm (Huiskes 1980).

Less tissue damage in using cement with reduced heat production has been found indirectly by Mjöberg (1986), who, by roentgen stereophotogrammetric analysis, found less prosthetic migration using a new cement with less heat production. A slightly reduced heat generation has been shown by vacuum mixing the bone cement (Lidgren et al. 1987). Seidel et al. (1977) could lower the maximum temperature from 59 to 45 °C by cooling the bone with ice water; and Meyer et al. (1973), in vitro, could lower the maximum cement temperature by lowering the ambient temperature.

The size of the cement mass has an important rolein heat generation (Huiskes 1980, Huiskes and Schlooff 1981, Mjöberg et al. 1984), but we could not find any correlation between the size of the cement mass and the temperature rise. This may be explained by the low precementation temperature in the bone, the relatively thin cement layer, and the fact that the bone surface is not smooth, which makes the area for heat transportation large, and, together with the local blood flow, could minimize the heat generation.

The problem with heat generation during the cement-curing process could be the time during which the temperature exceeds the limit for impaired bone regeneration. The longest duration of a temperature exceeding 44 °C was 4 minutes and 50 seconds in the acetabular region and 7 minutes in the femoral region.

We believe the main reason for the relatively small number of damaging temperatures was the low ambient bone temperature. The temperature at the beginning of the curing time is often stated to be 37 °C. In our investigation, this temperature was 32 °C in the acetabulum and 29 °C in the femur. This may be the explanation of the slightly higher curing temperature in the acetabulum and why only seven of our measurements were above the critical level. Our results show that the heat generated using the lowest known temperature border in 13 percent of the cases exceeded the limit for impaired bone regeneration. Further efforts to decrease the temperature seem appropriate.

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