Temperature elevation during knee arthroplasty

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The temperature in the tibia and in the saw blade were recorded during 30 knee arthroplasty operations. In the saw blade the median maximum temperature was 68 °C (45–100 °C). The corresponding bone temperatures at two levels approximately 2 and 3 mm below the cutting surface were 47 °C and 42 °C, respectively. Irrigation of the saw area with physiologic saline solution had only a minimal effect. During the cement-curing process, the temperature was 37 °C (31–50 °C) at the cement-bone interface. We conclude that the cutting procedure generates heat above the critical temperature for bone necrosis that may harm prosthetic fixation, notably for bone ingrowth.

Roentgen stereophotogrammetric analysis has disclosed micromotion of all the tibial components in knee arthroplasty (Ryd 1986). In accordance with histologic studies (Haddad et al. 1987), bony ingrowth was concluded not to occur in noncemented prostheses (Ryd et al. 1989).

When preparing bone with power tools, high temperatures causing bone necrosis may arise (Matthews and Hirsch 1972, Krause et al. 1982a, Eriksson 1984). Necrosis caused by the cutting of the cortical and subchondral bone, which are often extremely hard in arthrotic knees, could be one reason for micromotion and lack of bony ingrowth (Rhinelander et al. 1979, Ryd 1986).

During knee arthroplasties for gonarthrosis, we measured the bone and saw-blade temperatures while cutting the tibia, as well as the temperatures during the curing of the cement under the tibial component.

Patients and methods

The temperature measurements were performed with copper-constant thermocouples (Exacon CN 7, Exacon Scientific Instruments Aps, Roskilde, Denmark) connected to a pen recorder (BBC SE 460, Brown Boveri Goerz Metrawatt, Vienna, Austria), with a temperature measuring range of 0–100 °C (accuracy ±1.0 °C).

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A thermocouple was embedded in three new oscillating saw blades (3M Maxi Driver™ Blade L 122, Orthopedic Products Division 3M, St Paul, MI, U.S.A.), with the measuring point 2 mm from the cutting edge.

Two thermocouples were inserted into the tibia underneath the cutting surface. To achieve this, the jig #V-B of the P.C.A.™ Universal™ Total Knee Instrument System (Howmedica, Rutherford, NJ, U.S.A.) was modified with a number of holes 1 and 2 mm below the upper guiding surface. These holes guided Steinman pins of appropriate dimensions, used as drill bits (Figure 1). The redundant number of holes made it possible to chose a region of measurement corresponding to the area of most pronounced bone attrition and sclerosis, which we postulated should give the highest temperatures. Because of technical difficulties, we could not achieve three parameters (saw blade, 1 and 2 mm) in all operations.

A methodologic study was carried out with 17 different insertions of 6 cadaver knees, where the position of the thermocouples with reference to the subsequent cut surface was verified using the same operative procedure. Bone blocks were removed for radiographic examinations with Steinman pins used as markers for the thermocouples. The tips of the Steinman pins at the 1- and 2-mm levels were found to be situated 1.8 (0.2–3.5) and 3.4 (1.5–5.0) mm from the cut surface, as measured 30 mm from the anterior tibial cortex, corresponding to the clinical situation. These levels are referred to as the 2- and 3-mm levels.

Thirty temperature measurements were carried out in vivo when preparing for the P.C.A.™ tibial component in knee arthroplasty for arthrosis. There were 18 primary operations: seven with the unicompartmental

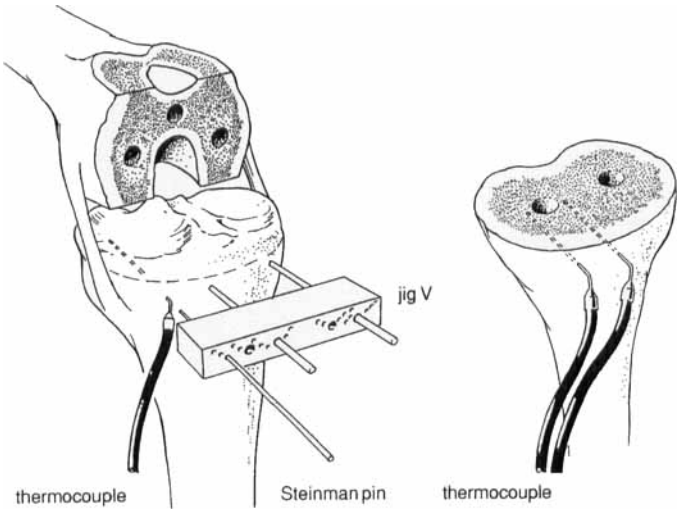

Figure 1. Insertion of thermocouples into the tibia for recording temperatures during sawing and during cementation.

and 11 with the tricompartmental knee prosthesis. Ten operations were revisions after five previous osteotomies and five prosthetic operations with nine tricompartmental prostheses and one unicompartmental prosthesis. Two cases in which additional cutting was done were included in the revision group. The operations were always performed according to the manual using the P.C.A. instrument system.

On nine occasions, attempts were made to cool the sawing area. Irrigation with 50–100 mL of physiologic saline was applied to the anterior part of the tibia with a plastic syringe. During all the measurements the cooling agent was applied from the beginning of the cutting process.

In the 19 cases where cementation of the tibial component was performed, a second temperature recording was made during the curing process. Two thermocouples were arbitrarily inserted in the tibial metaphysis in an oblique cephalad direction, so that their tips came to lay flush with the upper cut surface, i.e., in close contact with the prosthesis after insertion. Cement was applied after lavage in a precooled state (4 °C) using the pressurization technique (Halawa et al. 1978, Miller et al. 1979, Ling R. S. 1986, Lidgren 1988). In this way, a 2–4-mm cement-cancellous bone sandwich was created (Krause et al. 1982b), where cement totally embedded the tip of the thermocouple. In 1 case a bone cyst, 20 x 7 x 20 mm, was filled with cement; in this case the thermocouple was placed flush with the cyst wall about 3 mm below the upper tibial surface.

Results

The overall median maximum temperature in the saw blade was 68 °C, and the overall median maximum temperatures at the 2- and 3-mm levels were 47 °C and 42 °C, respectively (Table 1). Irrigation did not lower these temperatures.

The median maximum temperature during the cement-curing process was 37 °C (31–50 °C). The highest temperature was recorded in the case with a bone cyst. The median bone temperature was 32 °C (27–37 °C) at the beginning of the cutting procedure and 30 °C (26–36 °C) before the cement-curing process.

Table 1. The median maximum temperature °C (range) in the saw blade and in the tibia during bone cutting in knee arthroplasty

	Saw	2 mm	3 mm
All	68 (44–≥100) n 27	47 (27–70) n 23	42 (27–69) n 21
Primary	65 (44–95) n 18	49 (33–70) n 14	40 (31–55) n 13
Revision	74 (49–≥100) n 9	45 (27–54) n 9	44 (27–69) n 8
Without cooling	68 (44–≥100) n 18	48 (27–68) n 14	43 (27–69) n 15
With cooling	69 (50–95) n 9	47 (35–60) n 9	39 (33–46) n 6

n number of cases in each subset.

Discussion

Contrary to heat generation from curing cement (Labitzke and Paulus 1974, Reckling and Dillon 1977, Seidel et al. 1977, Holm 1980), the thermal trauma during bone cutting has received little attention, although most surgeons recognize the odor of burnt bone.

Eriksson et al. (1983) have shown that bone tissue is more sensitive to heat than previously postulated: Heating to 47 °C for 1 min severely impaired the bone formation. The temperature in the range of 44–47 °C was regarded as the threshold temperature for impaired bone regeneration (Eriksson 1984). We regularly found temperatures exceeding 37 °C.

Variations in temperature in the saw area may depend on the density and architecture of trabecular bone. We did not attempt to analyze such causes of temperature variations. A great deal of the heat production during sawing occurs when the chips are formed; in metal cutting operations the heat accumulated in the chips comprises two thirds of the total heat (Schmidt 1950). In clinical bone-cutting procedures, most chips are retained, a factor that may increase the temperature and equalize local differences between sclerotic and nonsclerotic areas.

We are aware of only one report dealing with the sawing of human bone in vivo. Krause et al. (1982), using a reciprocating saw, reported temperatures without irrigation exceeding 200 °C during total-hip replacement. When irrigation was applied with a syringe, the temperatures dropped rapidly. During osteotomies in the lower jaw of cats, temperatures up to 300 °C have been recorded (Tetsch 1974).

In our study no benefit from attempts to cool the cutting area was found. This is in contrast to Ludewig (1971), who could lower the saw-blade temperature from over 100 °C to less than 50 °C when cutting sheep femurs. The explanation for the difference may be that the cooling effect in our study did not penetrate into the interior of the bone when the actual cutting took place. Also the chips from the kerf of the saw blade were not cleared away. For this reason, we conclude that routine attempts to cool the cutting process during knee arthroplasty are inefficient.

Only on one occasion was the temperature greater than 47 °C. It was when the thermocouple was placed at the bone-cement interface of a bone defect filled by cement, well in agreement with the observation made by Mjöberg (1986). Huiskes (1980) has mathematically described the heat generation and conduction of acrylic cement in situ in hip arthroplasty; he concluded that the maximal bone temperature will probably not be higher than 60 °C. The heat produced during the cement-curing process is correlated with the volume of the filling (Mjöberg 1986). In knee-prosthetic surgery, this heat should be less than in hip-prosthetic surgery because the amount of cement is far smaller—indeed, only a thin film between the bone and the prosthetic component.

True bone anchorage, osseointegration, requires minimal tissue trauma (Albrektsson 1980, Albrektsson et al. 1981). In prosthetic devices aiming at bony ingrowth into porous surfaces or at a stable fibrous interface only, the prerequisites may not be as strict; but it seems reasonable to avoid thermal necrosis also in these situations.

We conclude that the bone-cutting process as used during knee arthroplasty may cause substantial temperature trauma. This heat generation may contribute to loosening of the tibial component.

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