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Heat caused by drilling cortical bone

Temperature measured *in vivo* in patients and animals

In vivo temperature measurements were performed at drilling in the femoral cortex of the rabbit, dog and man. In the clinical study the bone temperature was measured at fixation of a Richards plate to stabilize a pertrochanteric fracture. With a drill speed of around 20 000 rpm and saline cooling, temperatures of 40°C in rabbits, 56°C in dogs and 89°C in patients were recorded at a distance of 0.5 mm from the periphery of the drill hole. The difference in temperature between the animal and clinical studies was mainly attributed to the difference in cortical thickness between the species. When drilling straight through the canine femur from the lateral to the medial side, a 9°C higher temperature was measured in the remote, medial cortex compared to that recorded in the lateral cortex. This difference arose because it is difficult for the cooling agent to reach the medial cortex. The results of the present study indicate that temperatures measured in animal experiments are not applicable to the clinical situation where very high temperatures may arise on drilling in cortical bone, even if saline cooling is used.

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Experiments dealing with bone temperature measurements found in the literature are performed either on animals or on human cadaver bone. Hence there are no reports of the temperature rise at a clinical bone-cutting procedure.

The aims of the present investigation were:
(1) To measure the temperature rise at drilling in the femoral diaphysis of the rabbit;
(2) To compare the temperature rise at drilling in the lateral canine femoral cortex to that measured in the medial, remote cortex of the same animal;
(3) To measure the temperature elevation when inserting screws for a Richards plate under clinical conditions.

Material and methods

Rabbit study

Five adult New Zealand white rabbits, weighing 3.0–4.3 kg, were used in the experiment. Anaesthesia was induced and maintained with intramuscular injections of Hypnorm® (Fluanison and Fentanyl, Leo, Helsingborg, Sweden) at a dose of 0.7 ml/kg body weight. The diaphyses of the right and left femurs were exposed by straight incisions of the skin and fascia. The periosteum was denuded with a surgical scalpel. All operations were carried out under clean but not aseptic conditions.

A special drill guide was used to ensure a fixed distance of 0.5 mm between the test drill and the heat-sensitive thermocouple (Figure 1). A hole, 0.8 mm in diameter and 1 mm in depth, was drilled in the cortex under ample saline cooling. A thermocouple was inserted through the drill guide and located in the previously drilled hole. Test drilling was performed in one session through the 1.5 mm thick cortex of the femur. Two experimental holes were drilled in each femur. The test drill used was a new twist drill, 3 mm in diameter with a point angle of 118° and helix angle of 30° and driven at a free running speed of about 20 000 rpm as indicated by the stroboscope measurements performed. Saline cooling was continuously ensured via a syringe connected to the drill guide. The agent was kept at room temperature and irrigation was done at an irrigation rate of 60 ml/min.

The temperature rise was measured with a thermocouple, 0.7 mm in diameter, connected to a thermometer, Exacon MC 9200, (Exacon® scientific instruments ApS, Taastrup, Denmark) with an accuracy of ±0.1°C and response time of 0.5 s. The measuring device was checked against a laboratory mercury thermometer at each temperature measurement. The signals were linear throughout the measuring range.

The thermocouple consisted of two 0.25 mm leads coated with thermovarnish in order to prevent heat conduction along the leads. To further reduce this risk, they were covered with a silicone sleeve. Thus, in order to reduce the measuring error, the thermocouple used was only able to measure the temperature at the very tip.

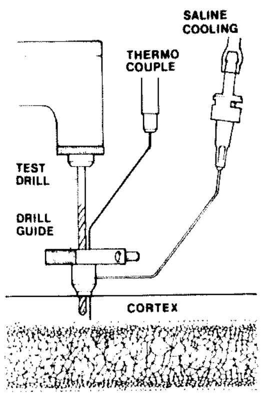

Figure 1. Illustration of the experimental set-up at drilling in cortical bone of the rabbit and dog. A drill guide is used to ensure a fixed distance of 0.5 mm between the test drill and the heat-sensitive thermocouple. Irrigation is applied via a syringe connected to the drill guide.

Dog study

Two adult beagle dogs were operated on under general anaesthesia induced by intravenous injection of Ketalar® (Ketamin, Parke-Davis, New Jersey, USA), 10 mg/ml, at a dose of 3 mg/kg body weight. The anaesthesia was maintained by infusion of a mixture of 1000 mg Ketalar®, 50 mg/ml, and 500 ml glucose, 5.5%, at a dose of 5 mg/kg body weight per hour. The dogs were intubated during surgery and artificial respiration was maintained via a respirator.

An identical approach to that used in the rabbit study was used at surgery and when measuring the temperature elevation at drilling. However, temperature measurements were performed in the lateral and medial cortices of the same femur. The measuring depth was 3 mm in both the lateral and medial cortices. The drilling conditions were similar to those described previously.

Clinical study

Temperature measurements were performed in the proximal, femoral diaphysis of five adults, 60–70 years of age, who had pertrochanteric fractures stabilized by means of internal fixation with Richards 4-hole plates. After fixation of each plate with the proximal lag screw and a cortical screw inserted through the distal hole, two proximal holes in the plate were utilized to stabilize a drill guide used in the experimental drilling procedure.

In order to ensure a defined distance between the test drill and the heat-sensitive thermocouple, a specially constructed drill guide identical to the one used in the animal experiments was used.

A twist drill, 0.8 mm in diameter, was run through the drill guide which was attached to the Richards plate. A hole was then drilled in the lateral cortex of the femur as deeply as possible without penetrating to the marrow cavity, which was ensured by X-ray transillumination. Thereafter, the thermocouple was inserted through the drill guide into the cortical hole. The same measuring equipment as in the animal experiments was utilized in the clinical experiment. A new twist drill, 3 mm in diameter, run at a speed of 20 000 rpm was then inserted into the wider canal of the guide and the test hole was drilled without interruption through the femoral cortex under simultaneous temperature registration. The measuring depth was around 6 mm. All drilling was performed under continuous saline cooling through the elastomer tubing. The temperature of the saline solution was 22°C and the irrigation rate 60 ml per minute.

After the temperature registration, the 3 mm-wide test hole was used as a guide hole for the wider screw for fixation of the Richards plate.

The effectiveness of the cooling system of the drill guide was compared with the efficacy of conventional, external irrigation in an *in vitro* experiment. No significant differences were noticed between the two cooling systems. The level of significance was tested with a sign test.

Results

A total of 20 measurements was carried out in the rabbit experiment. The mean temperature recorded was 40°C ± 1.1, i.e. a temperature increase of, on average, 8°C from the initial temperature. The temperature rose very quickly during drilling, and only a very short time lag was noted before peak temperature was recorded. When drilling ceased, the temperature fell abruptly to the initial temperature, 32°C. Drilling time, i.e. the time for penetrating the cortical bone, was around 5 s.

Altogether 10 measurements were undertaken in the femur of the dog. The cortical thickness was on average 3.5 mm. The duration of the peak temperature lasted only a few seconds and fell rapidly when the marrow cavity was reached. The initial temperature was 32°C. After drilling for around 15 s, the lateral cortex was penetrated and the temperature recorded was 56°C ± 1.8 at a distance of 0.5 mm from the periphery of the drill. The initial temperature in the remote, medial cortex was the same as in the lateral cortex. The peak temperature recorded in the medial cortex was 65°C ± 3.4, i.e. almost 10°C higher than the temperature noticed in the lateral cortex.

In the clinical study two measurements were carried out in each of five patients. In all cases it was possible to hold the guide in a firm grip during the drilling procedure. The drilling was done in one session, without interruption. The mean time taken to penetrate the cortex was 18 s. The temperature recorded was 89°C ± 4.9 and the maximal temperature was 96°C, even though saline cooling was applied. The cortical thickness was around 6.5 mm.

Discussion

The literature review reveals that the temperatures recorded at bone drilling vary considerably. This may be partly explained by the fact that the experimental conditions could be very different from one test situation to another depending on, for instance, better or poorer control of surgical parameters such as the condition and geometry of the drills, the drill speed and the applied pressure. Another reason for the varying results in previous investigations is indicated by the results of the present study. The mean temperature in the rabbit was 40°C and in the dog femur 56°C (lateral cortex), while drilling in the living human femur caused a temperature elevation to, on average, 89°C. This difference in temperature reflects mainly the variation in cortical thickness between the species, even if possible differences in drilling techniques between the experimental and the orthopaedic surgeon may have influenced the results to some extent (Hobkirk & Rusiniak 1977). The mean cortical thickness of the human femur was 6.5 mm, compared to 3.5 mm and 1.5 mm for the dog and rabbit, respectively. The importance of the cutting depth for heat generation has been pointed out in other experiments (Tetsch 1974, Krause 1977, Krause et al. 1982), although this is the first time that figures from drilling in live human bone have been presented. We find the temperature elevation in the human femur to be great, considering that a controlled cooling system was used in the present experiment. Wiggins & Malkin (1976) observed that the flutes of twist drills may tend to clog when the depth of the drill hole is increased. This leads to a substantial increase in torque and specific cutting energy and may be one reason, apart from the increased drilling time, for the elevation of the temperature. Another reason may be that it is difficult for the cooling agent to reach the point of the drill when it is buried deep in the cortex. This was indicated by our canine experiment where the temperature elevation observed in the lateral cortex was compared to that observed in the medial, remote cortex, all other factors being controlled. The temperature recorded in the medial cortex was around 9°C higher than in the lateral cortex which the cooling agent was better able to reach. An even greater temperature difference would be expected when drilling in the lateral and medial cortex of man. One theoretical way of counteracting this problem would be to use internally cooled burrs, although such devices have shown a tendency to debris plugging.

The peak temperatures recorded here clearly exceed, at least in the femoral cortex of the dog and man, the threshold temperatures for bone tissue injury. Even short (seconds) exposure to temperatures around 90°C is sufficient for the establishment of bone necrosis (Eriksson 1984).

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