The effect of drilling parameters on bone

Part I  General healing response

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For biocompatibility evaluation, orthopaedic and dental biomaterials are often implanted into bone after drilling. Bone repair in the drilled hole may be affected by bone damage attributed to drilling, thus influencing the bone response to biomaterials. The drilling parameters (the speed of rotation and irrigation) were investigated histologically. Three holes were drilled in each rabbit tibia with different conditions; three speeds (200, 500 and 5000 r.p.m.) and the use of central irrigation or not. Rabbits were killed immediately, 3 days, 2 weeks or 4 weeks post-operatively. India ink was injected in several rabbits just after drilling to investigate the extent of local ischaemia. The drilling quality was evaluated with regard to hole geometry, initial thermal damage and later bone healing process.

For 500 or 200 r.p.m. the initial thermal damage, shown by the degree of ischaemia, was less than for 5000 r.p.m. drilling, but the hole edge was not always cleanly cut. This uneven cut edge was considered not to influence the bone-healing process. Drilling at 200 r.p.m. introduced a lower degree of circularity. The subsequent bone formation was retarded by 5000 r.p.m. drilling, presumably due to thermal damage and vascular obstructions. The irrigation was effective in reducing the ischaemic area. These results suggest that a speed of about 500 r.p.m. may be recommendable for intra-osseous implantation of biomaterials. The central irrigation system is considered effective in reducing the ischaemic area.

1. Introduction

The response of bone to orthopaedic biomaterials is a matter of concern, and its evaluation is usually performed by inserting cylindrical implants into drilled cortical defects. However, the bone response may be affected not only by the implant itself, but also by the implanting conditions. Drilling is an important factor of the implanting conditions. One of the most serious problems in drilling is heat production. A high temperature causes osteonecrosis around the hole, which may affect the bone-healing process and may deleteriously influence the response of bone to implanted materials. Non-cylindrical drilling induces various amounts of bone-implant gap and may impair the implant stability, introducing another factor of variability into the bone-implant relationship.

Drilling in bone has been analysed from several points of view. The required cutting force, heat production and bone damage are the main parameters to be considered when evaluating the drilling performance. The drilling quality is determined by the following factors: the drill geometry and material, the speed of rotation, the torque, the applied force, the use of irrigation, predrilling (i.e. drilling with a drill of smaller diameter before drilling with the definitive diameter) and, finally, the cortical thickness and bone density.

Concerning the drill geometry, several types of twist drills have been investigated [1–4]. Hobkirk and Rusiniak [5] compared six different types of drills and burrs. A spear-point drill and a twist drill were preferred.

Thompson [6] studied the influence of the speed of rotation (from 125 to 2000 r.p.m.) both by histology and by measuring the temperature in vivo. A speed over 1000 r.p.m. caused greater temperature elevation and greater thermal damage around the hole, whereas a speed below 250 r.p.m. increased the degree of fragmentation of the hole edge. Accordingly, a speed of about 500 r.p.m. was recommended to reduce the initial damage.

The temperature elevations during drilling have also been measured in vitro [7]. The maximum temperatures were not significantly different among three speeds of rotation, 345, 855 and 2900 r.p.m. Ultra-speed drilling, over 200000 r.p.m., has been recommended for clinical evaluation [8], by temperature measurement [9] and by histological examination of the bone-repair process [10–12].

Mathews and Hirsch [7] also studied the influence of both the applied force and predrilling. They found that an increase in the applied force was associated with a decrease in the maximum temperature, and the use of predrilling limited the temperature elevation.

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With one exception [13], the use of irrigation has been demonstrated to limit the temperature elevation [7, 9] and to decrease the bone damage [10, 11]. A flow rate of > 500 ml min⁻¹ has been reported to be necessary to obtain sufficient effect for cooling [7]. In order to reinforce the effect of irrigation, Eriksson et al. [14] recommended the use of internally cooled burrs, which enable the cooling agent to reach the cutting site directly.

By comparing rabbit, dog and human cortical bones, the cortical thickness as well as the bone density have also been reported to influence the temperature elevation attributed to drilling [14].

When drilling bone defects for biomaterial testing, the geometry of the defect and the bone-healing process affected by the thermal damage may be considered as the main parameters that must be taken into account. From the previous literature, the drilling conditions have been evaluated mostly by focusing on initial damage. Few studies have looked at the bone-healing process histologically over a time period, and the insufficient histomorphometrical techniques have limited a precise quantitative evaluation. This study was performed to investigate histomorphometrically the influence of the speed of rotation and irrigation on the resultant hole geometry, initial thermal damage and later healing process by using an image-analysing system.

2. Materials and methods

2.1. Drilling conditions
A semicircular, 4.0 mm diameter drill (IMZ 514021, France-Implants, Vincennes, France) was used (Fig. 1). The drill was driven by a motor system (AFU-717, Aseptico, Washington, USA), which could variably control the speed of rotation (from 100 to 15 000 r.p.m.) and which had an irrigation pump. The speed of rotation was digitally indicated on the front panel. Physiological saline at room temperature (20–22 °C) was used as the irrigation agent and flushed out from the centre of the drill at a flow rate of 60 ml min⁻¹. Six different drilling conditions were created by the combination of three speeds of rotation (200, 500 or 5000 r.p.m.) and the use of irrigation or not.

2.2. Animal experiments
Twenty-three male New Zealand White rabbits, weighing about 3.0 kg, were used. General anaesthesia was induced and maintained by intramuscular injections of Zoletil (Zolazepam + Tiletamine; 20 mg kg⁻¹ body weight) and Rompun (Xylatine; 0.2 mg kg⁻¹ body weight). The operation was performed under aseptic conditions. Both legs were shaved, cleaned and disinfected. In each hindlimb, a 3 cm longitudinal skin incision was made on the anteromedial surface starting from the distal portion of the tibial tuberosity. The M. tibialis anterioris and M. extensor digitalis pedis longus were separated and the tibia was exposed supraperiosteally. Three holes were drilled in the diaphysis of each tibia, perpendicular to the cortical bone. The drilling condition of each hole was distributed at random. After drilling, bone debris was carefully removed by irrigation in all holes. Muscles, subcutaneous tissues and skin were closed layer by layer. A sterile dressing was applied. After surgery, all rabbits were kept in individual cages and immediate weight-bearing was allowed.

Rabbits were distributed into four groups which were killed immediately, 3 days, 2 weeks or 4 weeks after surgery. Tibiae were fixed in 10% buffered formalin, then dehydrated and embedded in methylmethacrylate. The tibiae were each cut into three parts containing one hole in each block. Each block was cut into a slice with a diamond saw blade, perpendicular to the drilling axis, parallel to the cortical bone at the middle level of cortical thickness (Fig. 2a). The slices were ground down to 100 µm and stained with Paragon. The number of available specimens for each group is listed in Table I.

Another five rabbits were used to investigate ischaemia by using India ink. The operative technique and the drilling conditions were similar to those described above. After the drilling procedure, the abdominal aorta was exposed and was cannulated in the distal direction. First, 5 ml 2% Xylocain was injected.

![Figure 1](image-url) Semantic drill used in the experiment. The irrigation tube is connected to the nozzle inserted in the centre of the drill.

![Figure 2](image-url) (a) Tibia cut into slice, parallel to the cortical bone at the middle level of cortical thickness and (b) tibia cut transversely for the India ink-injected specimens.