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Investigation of the effect of movement and irrigation systems on temperature in the conventional drilling of cortical bone

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Abstract

We have compared the results of the external irrigation technique with those of a double irrigation technique with continuous intermittent movement. Maximum thermal measurements were made in the cortical part of 10 samples of bovine ribs during osteotomy to simulate the preparation of a surgical bed for the installation of dental implants at a depth of 10 mm. Twenty specimens were drilled for each group: external irrigation and continuous movement (control group 1, CG1); external irrigation and intermittent movement (control group 2, CG2); double irrigation and continuous movement (test group 1, TG1); and double irrigation and intermittent movement (test group 2, TG2). The double irrigation technique gave significantly better results regardless of the drilling movement used. Thermal increases between samples was 19.2% in group CG1, 10.4% in CG2, 5.4% in TG1, and 3.4% in TG2. The double irrigation technique produced a significantly smaller increase in temperature in the cortical bone during both types of drilling ($p = 0.001$), which illustrated its greater efficiency compared with that of the external irrigation technique.

Keywords: Osteotomy; Bone surgery; Thermocouple; Dental implants; Irrigation

Introduction

Bony tissue is heated by the friction contact of the drill against bone during the preparation of the surgical bed. The generation of excessive heat may cause thermal necrosis of the bone, which directly interferes with biological stability through the deterioration of the organic portion of the bony tissue and differentiated and undifferentiated cells in the local circulation.[1]

Thermal damage at the drilling site prevents regeneration because of the low thermal conductivity of the cortical bone. The heat is dissipated slowly, but is maintained around the osteotomy, which may induce necrosis, fibrosis, bony cystic degeneration, and a reduction in osteoblast activity.[2] The structure and vascularisation of the bone are relevant to the reaction of bone to heat. Medullary bone dissipates heat more quickly and has a better capacity for regeneration than cortical bone, because it possesses a richer cellular and molecular supply. The temperature limit of undamaged tissue during repair is 44–47 °C for 1 min.[3]

Different cooling techniques are used to control the increases in bone temperature caused by friction of the drill during osteotomy. External irrigation disperses irrigation solution over the cortical bone.[4–6] The internal irrigation technique applies the irrigating liquid through a hole in the

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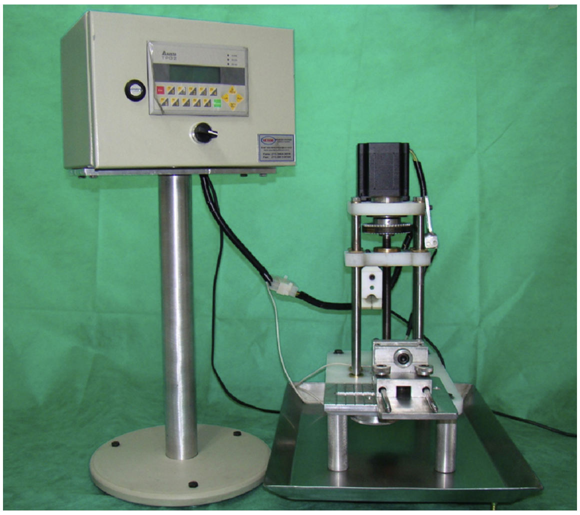

Fig. 1. Equipment designed for the experiments.

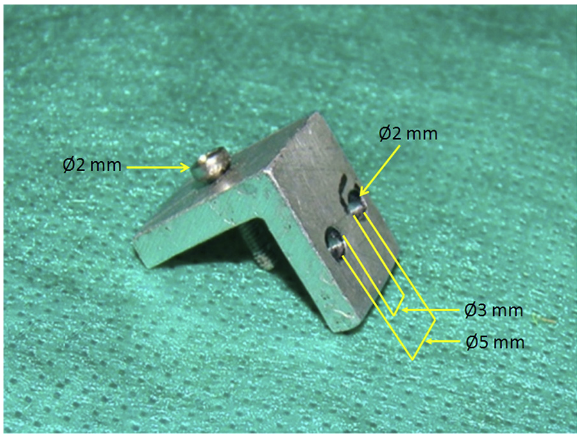

Fig. 2. The piece used as a surgical guide.

interior of the drill.[5,7] The double irrigation technique is a combination of the two techniques.[8]

There are several ways to measure the temperature of bone during osteotomy. Infrared thermography is an indirect way of measuring the temperature of the surface of a body using a colour scale.[4,9] Thermopairs may also be installed near the sites at which the bone is drilled.[6,8,10,11] The thermopairs use the differentiation of electrical potential between 2 metals to report the temperature where the terminations are installed in °Celsius. Tables indicate the tension that is produced by each type of thermopair at each temperature. For example, the type K thermopair measures temperatures of −200 to 1372 °C with a precision between 0.1% and 0.7%.

In this in vitro study we have measured bony temperatures in samples of rib during continuous and intermittent drilling to compare the results of the external irrigation technique with those of the external and internal double irrigation techniques.

Materials and methods

A special unit was developed to ensure surgical conformity that included a control panel, a programmable logic controller, a step motor, and a man/machine interface. An encoder and step motor were installed to produce intermittent and continuous drilling movements with pre-established high-precision patterns in time, positioning, depth, and load in all experiments. The apparatus stabilised the samples of bone during drilling and avoided human interference, which reduced possible variations in the results (Fig. 1).

The programmable logic controller uses a programmable memory to store instructions internally and implement specific functions, such as logic, sequence, timing, counting, arithmetic, and control, using several machines and processes as input and output modules.

The step motor is a transducer that converts electrical pulses in mechanical rotational movements to produce a raised torque/unit of rotor volume with total digital adaptation of several programs. A surgical engine for the implants was adjusted to a speed of 1200 rpm, torque of 35 N, with identical dispersion of 50 ml/min irrigation liquid (a physiological solution) at room temperature. The surgical engine was coupled to a counter angle with a 1/16 reduction and an established 2 kg load.

Two helicoidal 2.0-mm drills made the perforation (Implacil De Bortoli Produtos Odontológicos Ltda., São Paulo, Brazil). One drill was used for external irrigation, and the other contained an internal orifice for internal irrigation. Four groups were created to enable better understanding of the data. The external irrigation groups were the controls because this is the more commonly used and described method. Control group 1 (CG1) = external irrigation and continuous movement; control group 2 (CG2) = external irrigation and intermittent movement; test group 1 (TG1) = double irrigation and continuous movement; and test group 2 (TG2) = double irrigation and intermittent movement.

A type K thermopair measured bony temperature. This was specifically fabricated in isolation and coupled to a portable digital thermometer (model 1200K – Salvterm) with a measurement range between −50 and +1300 °C and a resolution of 0.1–1 °C. The type K thermopair measured the temperature at the installation site (range −200 to +1372 °C) with a response time in seconds. The thermopair consisted of two metal alloys that united to generate electrical tension depending on the temperature.

Ten samples of bovine rib were acquired several hours before the experiment. Each rib was 8 cm long with a cortical width of roughly 3 mm. The samples were demarcated with a horizontal line between the extremities and 2 mm below the cortical bone. Orifices of 2 mm in diameter were created using a conical steel drill to make sure that adaptations of the type K thermopair were in proportion.

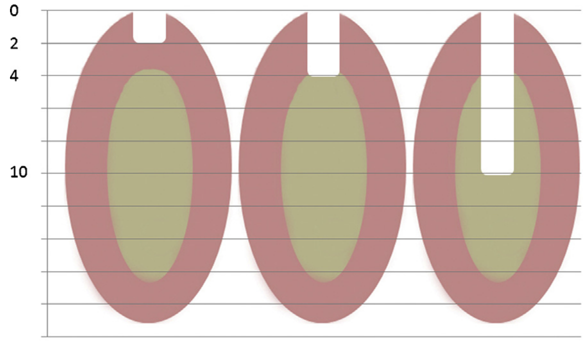

Fig. 3. Diagram of the sequence of intermittent milling depths.

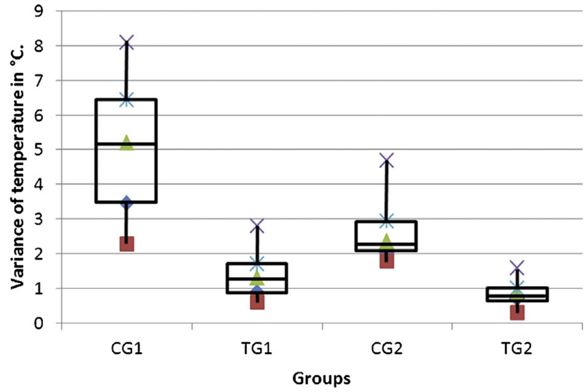

Fig. 4. Box plots of the temperatures of the holes in the proposed groups with different movements. Blue triangles = first quartile; brown squares = minimum value; green triangles = median value; purple X = maximum value; and turquoise asterisk = third quartile. CG1 = external irrigation and continuous movement; CG2 = external irrigation and intermittent movement; TG1 = double irrigation and continuous movement; and TG2 = double irrigation and intermittent movement.

A metal guide was made (Fig. 2) to demarcate the drill position in the cortical bone, the drill trajectory in the osteotomies, and the 3 mm distance between demarcations. The thermopair measured bony temperature at a distance of 0.5 mm lateral to the drill perforations.

The machine was programmed to intervals of 0–2 mm, 0–4 mm, and 0–10 mm deep in the intermittent movement drillings (Fig. 3). The time intervals of returns were 2 and 4 s at depths of 2 mm and 4 mm, respectively, for a total time of 20 s. The equipment was standardised to make perforations without return or time intervals to a depth of 10 mm for a total time of 9 s in the osteotomies with constant drilling movements. The maximum temperature in the cortical bone during each drilling was noted, compared, and evaluated statistically.

Results

All the data about drilling and temperature were collected in an electronic sheet, and the differences between the initial and final temperatures were calculated (Table 1). Fig. 4 shows the medians, quartiles, and ranges of the groups analysed.

The collected data were analysed with the GMC statistical program GMC (version 6.5 - 10/09/93. Prof. Geraldo Maia Campos, University of São Paulo), and probabilities of less than 0.05 were accepted as significant. The normality of the groups was analysed initially, and the results showed

Table 1
Temperatures obtained by continuous and intermittent movements during double irrigation and external irrigation.

Intermittent drilling				Continuous drilling			
Double irrigation		External irrigation		Double irrigation		External irrigation	
Initial	Final	Initial	Final	Initial	Final	Initial	Final
26.4	27.1	24.2	26.7	24.8	26.9	24	29.9
25.9	26.3	25.2	27.2	25.4	28.2	24.6	29.7
24.8	25.8	25	27.8	25	26.3	25.5	29.8
25.2	26.1	25.1	27.4	24.9	26.2	24.7	28.5
26.1	26.4	24.9	26.7	25.7	26.3	24.9	27.7
25.2	25.9	25.1	26.9	25.4	26.1	25.1	28.1
25.5	26.3	25	26.9	25.3	26.1	24.8	27.7
25.7	26.5	25.2	27.1	25.6	26.5	25.8	28.1
24.5	26.1	25.8	30.1	24.6	26.4	25.1	33.2
24.3	25.5	25.3	27.7	25.4	27.3	24.2	30.3
26.2	27.1	24.2	27.3	26.1	27.4	24.6	29.7
25.5	26.5	24.6	29.3	25.7	27.1	24.5	31.9
25.3	25.9	24.8	27.6	25.2	26.6	24.7	30.2
25.1	25.5	24.8	26.8	25	25.6	24.7	28.6
25.3	26.1	25.1	27.3	25.3	26.2	24.9	29.5
24.9	26.2	24.6	27.3	24.8	26.3	24.7	29.5
25.3	26.2	24.8	27.9	25.1	26.7	24.5	30.2
25.2	26.3	25.1	28.5	25.3	27.5	24.9	31.1
25.4	26.2	24.8	26.9	25.2	26.3	24.7	28.8
25.3	26.2	24.9	26.9	25	26.2	24.8	28.6
25.3 (0.52)	26.2 (0.41)	24.9 (0.36)	27.5 (0.88)	25.2 (0.36)	26.6 (0.61)	24.7 (0.39)	29.5 (1.40)

that the tested distribution was normal. The analysis of variance (ANOVA) with two factors was used: irrigation form (double irrigation and external irrigation) and drilling method (intermittent and continuous) and the ANOVA results showed significant differences for all comparisons (Table S2).

There were significant differences between the heat that was generated in the drillings with double irrigation and external irrigation ($p = 0.001$). Double irrigation produced a smaller temperature increase than external irrigation (1.11 °C and 3.68 °C, respectively). There was also a significant difference in temperature between the methods of drilling ($p < 0.001$). Perforations formed in a continuous fashion generated a mean heat that was greater than that formed by those generated in an intermittent fashion (3.07 °C and 1.72 °C, respectively).

We used Tukey's post hoc analysis to identify differences between samples. This showed that the numerical difference between the means of the interactions was significant ($p = 0.05$).

Discussion

The temperatures of bone in the current study were measured in osteotomies made in the cortical bone of samples of bovine rib, which were made using intermittent and continuous drilling movements and external double irrigation. The initial temperatures were compared with the maximum temperatures reached during the osteotomies. We developed an apparatus as a surgical unit to standardise the new method of doing the experiments using pre-established times and depths with precise movements of the positioning of the drills with intermittent and continuous movements. Comparisons between irrigation techniques improved the method. Previous research had compared the continuous and intermittent drilling movements using manual, but not standardised, methods.[12,13] Other studies have made osteotomies with a saw blade and external irrigation in sample blocks of bovine mandible in vitro and in vivo.[14] Previous osteotomies in samples of bovine rib have been done in vitro using 7 brands of drills and external irrigation.[12] Those authors concluded that intermittent drilling movements were important in the preparation of the surgical bed for the installation of bone-integrated implants.

The concern in doing traumatic operations remains, because the temperature of bone is a determining factor in reducing the possible injuries during the preparation of the surgical bed. Overheating is a risk in the region of cortical bone, where the tissue is more compact than in the medullary bone, which dissipates heat more quickly.[15] We therefore used only samples of cortical bone from bovine ribs. Thermal measurements were made using thermopairs, which are commonly used in this type of study.[6,8,10,15]

The present study developed new assay equipment that proportioned intermittent and continuous drilling movements at a load of 2 kg, which is similar to those used in previous studies.[7,8,16] A surgical engine was coupled to the apparatus and exerted a rotational speed of 1200 rpm and 35 N of torque, because velocity influences the generation of heat.[11,17]

Drills with or without internal orifices were used for double and external irrigation, respectively, in 40 osteotomies each, which is similar to the methods used in previous studies[18,19] on the use and wear of drills. Drills that are reused over 40 times produce an appreciable increase in temperature. We used bovine ribs because the density of the bone is similar to that of the human mandible. These samples therefore provided a good model for thermal analysis.[12] Samples of bone were acquired several hours before the experiment and adjusted to room temperature.

Measurements of temperature in the cortical bone were noted and analysed statistically to a 5% level of significance. The sample distribution was normal. Two-factor ANOVA was therefore used to assess the significance of differences between the means of irrigation (double and external) and the method of perforation (intermittent and continuous), and all possible comparisons differed significantly.

The internal orifice of the drill was not obstructed during the intermittent movement of the double irrigation. Bony fragments were seen on the drill for the double irrigation techniques with continuous drilling movements. There was obstruction in 2 samples, or 10% of the osteotomies. Bony fragments were seen on the drill during the external irrigation technique with intermittent drilling movements in 8 of the samples (40%). Bony fragments were seen on the drill during the external irrigation technique with continuous drilling movement in 18 samples (90%).

The double irrigation technique produced smaller increases in the temperature of bone compared with the external irrigation technique, regardless of the drilling movement, which suggested that double irrigation was more efficient. The efficacy of the double irrigation system in the present study is in contrast to previous reports.[5] We found no significant benefits in the temperature of bone between the conventional external irrigation technique and the internal irrigation technique.

The double irrigation technique is local and quick because the irrigating agent emerges from the drill and is applied directly in the bone. The fragments of bone tend to flow by the drill spires during irrigation, which diminishes the friction between drill and bone and promotes cooling and self-cleaning.[7] The efficiency of the double irrigation system in the control of temperature during osteotomy for insertion of implants was superior to external irrigation, primarily in cortical bony regions where compact tissue predominates.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.bjoms.2012.10.023.

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