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Intraosseous generation of heat during guided surgical drilling: an ex vivo study of the effect of the temperature of the irrigating fluid

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Abstract

We measured the rise in the intraosseous temperature caused by freehand drilling or drilling through a surgical guide, by comparing different temperatures of irrigation fluid (10 °C, 15 °C, and 20 °C), for every step of the drilling sequence (diameters 2.0, 2.5, 3.0, and 3.5 mm) and using a constant drilling speed of 1200 rpm. The axial load was controlled at 2.0 kg. Bovine ribs were used as test models. In the guided group we used 3-dimensional printed surgical guides and temperature was measured with a thermocouple. The significance of differences was assessed with the Kruskal-Wallis analysis of variance. Guided drilling with 10 °C irrigation yielded a significantly lower increment in temperature than the 20 °C-guided group. When compared with the 20 °C freehand group, the reduction in temperature in the 10 °C guided group was significantly more pronounced at all diameters except 3.5 mm. Finally, when the 10 °C-guided group was compared with the 15 °C groups, the temperature rise was significantly less at 2.5 and 3.0 mm than with the guided technique, and at 3.0 mm compared with the freehand technique. We suggest that the use of 10 °C pre-cooled irrigation fluid is superior to warmer fluid for keeping temperature down, and this reduces the difference between guided and freehand drilling.

Keywords: Irrigation fluid; Implants; Guided surgery; Drilling guide; Temperature; Bone drilling

Introduction

Keeping bony trauma to a minimum during preparation of the bed of an implant permits optimal conditions for osseointegration, which plays a key part in primary healing and so contributes to the long term success of dental implants.[1]

Drilling of bone is a common technique used in various types of surgery, and the generation of heat and associated mechanical damage during rotary cutting can influence the process of osseointegration. Previous studies have shown that necrosis can develop when the temperature during osteotomy exceeds 47 °C.[2,3]

In recent years progress in the field of guided surgery has accelerated, and static surgical guides are now common devices.[4,5] Misir et al. found that when a guide is used during drilling the increase in temperature is greater than when the implant site is prepared conventionally.[6] In another study, the

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difference between the guided flapless and flap techniques in terms of increase in temperature did not differ significantly.[7] Two other studies have shown that the heat caused by drilling in a surgical guide stays within the safe zone.[8,9]

To overcome thermal damage irrigation is essential [10,11] and, in particular, cold irrigation fluid has been found to be superior to fluid warmed to room temperature in minimising rises.[12,13]

However, to the best of our knowledge there has been no research into the use of irrigation solutions at different temperatures together with a surgical guide. We have previously found that with a higher drilling speed (1200 rpm) the rise in temperature could be near the necrotic threshold, so we wished to know if the use of saline solutions at various temperatures during guided surgical drilling at a speed of 1200 rpm would result in smaller rises.

Material and methods

Bovine ribs were used, because of their favourable thermophysical and anatomical characteristics. Davidson and James had already shown that bovine ribs are thermally isotropic, whilst their conductivity is identical to that of human mandible.[14]

The densities of the cortical and cancellous bone of bovine ribs have been shown to be analogous to those of human bone as measured by computed tomography,[15] and the study by Katranji et al. concluded that the mean edentulous and dentate cortical thickness falls between 1 and 2 mm, and 1.6 and 2.0 mm, respectively.[16] The thicknesses of our segments of bovine rib were within the same range. Sener et al. concluded that the increase in temperature was greater in cortical bone than in the deeper parts of the drilling cavity,[12] which has been confirmed by other studies.[17,18] Specimens of bovine rib bone with a cortical thickness similar to that of the human mandible were therefore used, and the measurements (which were made in the cortical layer of the bone) described the peak temperature during drilling.

Every specimen was taken from the same animal, and they were all stored at -10 °C in normal saline solution between the experiments, as described by Sedlin and Hirsch.[19] The animal was not killed for the experiment.

Our measurements were designed to replicate the rise in temperature during preparation of an implant site throughout a full drilling sequence (2.0, 2.5, 3.0, and 3.5 mm drilling), using a standard drilling speed (1200 rpm) and a standard quantity of external irrigation solution. The factors that were varied were whether the drilling was freehand or guided, and the temperature of the irrigating saline: 20 °C, 15 °C, or 10 °C. Each group was defined by the depth of drilling, the technique, and the temperature of the irrigant. Twenty-four groups were studied, and 20 measurements made in each group. In the groups in which guided surgery was evaluated we used a model surgical guide that had 2 × 5 guiding holes with metal sleeves (Fig. 1) and four holes for the fixing pins. Entry points for the freehand groups were marked on the surface of the specimens with the help of the surgical guide.

K-type thermocouples were used to measure temperature with a connecting measurement device (Holdpeak-885A, Holdpeak, China). The thermocouples were consistently placed into a well that had been prepared with a start drill 2.0 mm in diameter and a depth of 1.8 mm (so that we could make sure that the depth of the cavity never exceeded the cortical layer). The thermocouple was placed so that it touched the lateral bony wall of the cavity that was closest to the implant bed to be drilled and then tightly filled with bone chips derived from specimens of rib from the same animal, and the hole was thoroughly sealed with plasticine to maintain adequate insulation (Fig. 2).

Measurement cavities were positioned directly underneath the metal sleeve of the surgical guide, 1.75 mm horizontally from the 2.0 mm drilling canal, 1.5 mm from the 2.5 mm drilling canal, 1.25 mm from the 3.0 mm drilling canal, and 1.0 mm from the 3.5 mm (final) drilling canal (Fig. 2). To ensure comparable results, the measurement cavities were prepared in the same positions for the freehand groups. The precise position of the measurement cavities was calculated from a 3-dimensionally printed guide, which could be anchored with pins in the same position as the model surgical guide (Fig. 1).

A constant axial pressure was maintained throughout the procedure, and the axial load was controlled at 2.0 kg. Tehemar et al. had concluded that 2.0 kg can be considered as low hand pressure, [20] and this correlated with the observations of a recently-published systematic review by Möhlhenrich et al. which confirmed that 2.0 kg is the most extensively used axial load. [21] A bench drill (Bosch PBD 40, Bosch, Germany) with adjustable speed was used for drilling.

Before the measurements were made the specimens of bone were warmed to 37 °C in saline tanks, and we drilled only when the baseline temperature had fallen between 35 °C and 37 °C. Standard, constant, external irrigation generated by a commercially-available physiodispenser surgical unit (W&H Implantmed SI-923, W&H, Austria) was applied through a standard cannula (W&H, Austria) attached to the drilling machine and directed to the drill bit at a flow rate of 105 ml/minute. The temperature of the irrigation fluid was either 20 (1)°C (room temperature), or 15 (1) °C, or 10 (1) °C. Before each measurement the temperature of the saline solutions was checked with an infrared thermometric device (Holdpeak-320, Holdpeak, China).

The full experiment is shown in Fig. 3. Each one was made (and the full apparatus stored) in the same air-conditioned room at a temperature of 20 (1) °C. Temperature rises (peak temperature minus baseline temperature) were analysed statistically with the help of Statistica for Windows 10.0 (StatSoft, Tulsa, OK, now Dell Software Group, CA, USA). As the Shapiro-Wilk test indicated that the distributions were skewed, we used the Kruskal-Wallis analysis of variance for comparisons between groups.

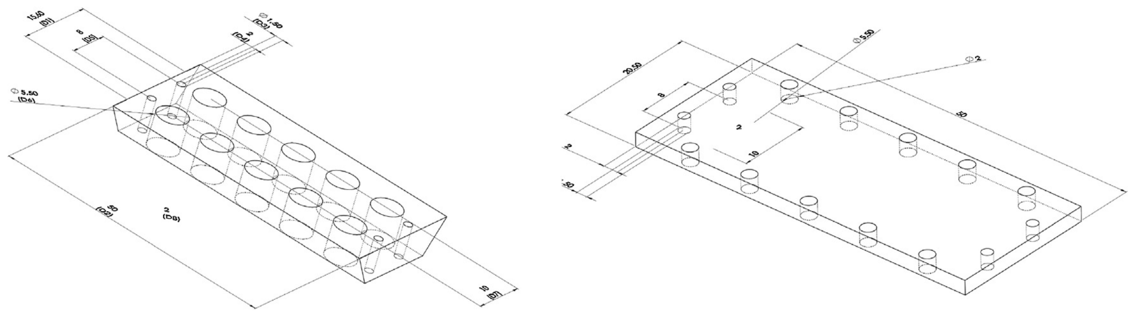

Fig. 1. The 3-dimensional printed surgical drilling guide (left) and the 3-dimensional printed guide to help measure the position of the cavity (right).

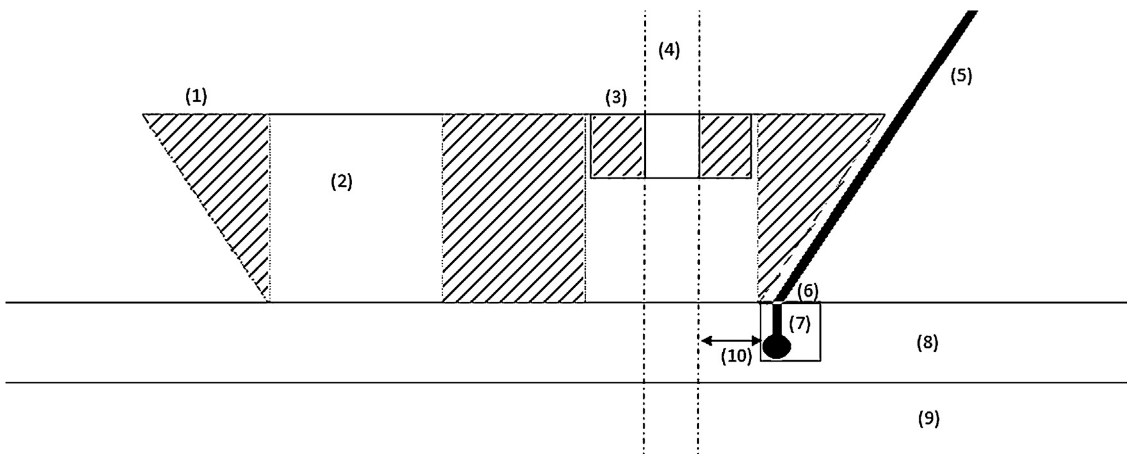

Fig. 2. Cross-section of the drill (1) = surgical drilling guide, (2) = drilling canal, (3) = drill sleeve for the actual diameter of the drill, (4) = projected drilling path, (5) = thermocouple, (6) = insulation, (7) = bone chips, (8)= layer of cortical bone, (9)= layer of cancellous bone, and (10) = distance from the canal to be drilled (1.75 mm for the 2.0 mm drill, 1.50 mm for the 2.5 mm drill, 1.25 mm for the 3.0 mm drill, and 1.0 mm for the 3.5 mm drill).

Results and Discussion

The results of our measurements are shown in Table 1. Data from the drilling procedures were divided into groups by the following aspects: temperature of the irrigation fluid, method of drilling, and diameter of the drill. The values of the thermal changes in each group are shown in Figure 4 (supplementary data).

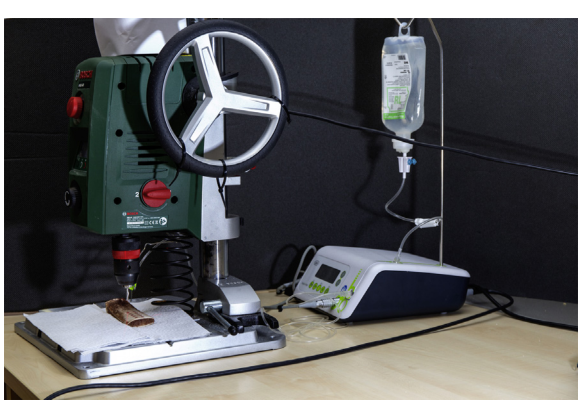

Fig. 3. The experiment.

There was a significantly smaller rise in temperature with freehand drilling with 10 °C irrigation compared with the 20 °C guided group **(p = 0.000 for all diameters),** regardless of the diameter of the drill. If freehand drilling with 10 °C irrigation was compared with freehand drilling with 20 °C irrigation, the difference between groups with the same drill diameter was significant **(p = 0.026 for 2.0 mm, (p = 0.000 for 2.5 and 3.0 mm),** with the exception of 3.5 mm drill diameter groups. When 10 °C freehand irrigation was compared with 15 °C guided irrigation, the difference was significant at 2.5 (**p = 0.005**) and 3.0 (**p = 0.004**) mm, indicating the superior efficiency of lower temperature irrigation.

Guided drilling with 10 °C irrigation also yielded a significantly lower temperature than the 20 °C guided group **(p = 0.000 for all diameters),** regardless of the diameter of the drill. When the 10 °C guided group was compared with the 20 °C freehand group, the reduction in temperature was significantly more pronounced at all diameters except for 3.5 mm (**p = 0.431 for 2.0 mm, p = 0.000 for 2.5 and 3.0 mm, whereas p = 0.055 for 3.5 mm** and **p = 0.??**). Finally, when the 10 °C guided group was compared with the 15 °C group, there were significantly lower rises in temperature at 2.5 **(p = 0.003)** and 3.0 **(p = 0.000)** mm compared with the guided technique, and at 3.0 mm compared with the freehand technique (**p = 0.025**).

Table 1
Mean rises in temperature for the examined groups showing the significant differences between groups with the same diameter of drill.

Group	Diameter of the drill	Guided/ free-hand	Temperature of irrigation fluid (°C)	Mean (SD) rise in temperature (°C)	Significant differences compared with groups with the same drill diameter (group number, * p < 0.05, ** p < 0.01, *** p < 0.001)
1	2.0	Free-hand	10	0.11 (0.61)	17*, 21***
2	2.5	Free-hand	10	0.15 (0.49)	14**, 18***, 22***
3	3.0	Free-hand	10	0.71 (0.96)	15**, 19***,23***
4	3.5	Free-hand	10	1.48 (0.74)	24***
5	2.0	Guided	10	-0.04 (1.15)	17*, 21***
6	2.5	Guided	10	-0.02 (0.80)	14**, 18***, 22***
7	3.0	Guided	10	0.10 (0.76)	11*, 15***, 19***, 23***
8	3.5	Guided	10	1.40 (0.58)	24***
9	2.0	Free-hand	15	0.66 (0.52)	21***
10	2.5	Free-hand	15	1.13 (0.51)	18*, 22**
11	3.0	Free-hand	15	1.75 (0.65)	7*, 23**
12	3.5	Free-hand	15	1.89 (0.70)	24**
13	2.0	Guided	15	1.44 (0.46)	-
14	2.5	Guided	15	1.85 (0.71)	2**, 6**
15	3.0	Guided	15	2.48 (0.91)	3**, 7***
16	3.5	Guided	15	2.75 (0.82)	-
17	2.0	Free-hand	20	1.74 (0.73)	1*, 5*
18	2.5	Free-hand	20	2.84 (1.19)	2***, 6***, 10*
19	3.0	Free-hand	20	3.11 (1.14)	3***, 7***
20	3.5	Free-hand	20	3.30 (1.52)	-
21	2.0	Guided	20	2.56 (0.92)	1***, 5***, 9***
22	2.5	Guided	20	3.45 (1.49)	2***, 6***, 10**
23	3.0	Guided	20	4.35 (1.36)	3***, 7***, 11**
24	3.5	Guided	20	4.86 (1.67)	4***, 8***, 12**

In all cases the drilling speed was 1200 rpm and the number of episodes of drilling was 20. For the grouping numbers marked with one *, the exact p-values rounded to three decimal digits are the following: Group 1: 17* (p = 0.026); Group 5: 17* (p = 0.043); Group 7: 11* (p = 0.025); Group 10: 18* (p = 0.031); Group 11: 7* (p = 0.025); Group 17: 1* (p = 0.026) and 5* (p = 0.043); Group 18: 10* (p = 0.031).

Kondo et al. concluded that cold irrigation might lessen the rise in temperature caused by drilling, [13] and the use of 10 °C irrigation could be better at keeping the temperature under the necrotic threshold. [12] Isler et al. concluded that the use of a 4 °C saline irrigation might result in better, quicker healing.[22]

Publications about the production of heat during guided surgery have so far studied only the use of normal saline at room temperature, and their findings may be summarised as follows. Misir et al. showed that a significantly higher peak in temperature could be measured during guided preparation of the implant site.[6] In a study in which they used resin models there was no comparable difference when they used a flapless or a flap approach during guided surgery.[7] An in vitro study by Migliorati et al. concluded that with proper irrigation, guided surgery can be as safe as the conventional method.[8] Dos Santos et al. also showed that the rise in temperature stayed within the safe zone when a surgical guide was used.[9] Finally, we have also shown that external irrigation can efficiently control the rise in temperature with the guided technique.[10]

A limitation of our study is that it was ex vivo. However, its strengths include the comparison of guided and freehand techniques, the use of saline solutions at different temperatures (10 °C, 15 °C, and 20 °C), drilling throughout a whole sequence of four different drill diameters with the same axial load, and the quantity of external irrigation being well controlled.

Conclusion

The use of saline as irrigating fluid at 10 °C meant that a significant reduction in peak temperature was achieved regardless of both the preparation technique of the site or the diameter of the drill. Considering our results that with irrigation at room temperature (20 °C) at a drilling speed of 1200 rpm, and a drill diameter of 3.5 mm, near-necrotic temperatures may be reached, we suggest that the use of 10 °C precooled irrigation fluid is a better way to control temperature.

Conflict of Interest

EV Jr. is the CEO, and EV is a consultant for and part-owner, of Dicom LAB Kft, Szeged, Hungary.

Ethics statement/confirmation of patient permission

No ethics approval was required as the research was done using samples of dead bone.

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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.2016.06.004.

References

1. Mishra SK, Chowdhary R. Heat generated by dental implant drills during osteotomy-a review: heat generated by dental implant drills. *J Indian Prosthodont Soc* 2014;**14**:131–43.
2. Eriksson AR, Albrektsson T, Albrektsson B. Heat caused by drilling cortical bone. Temperature measured in vivo in patients and animals. *Acta Orthop Scand* 1984;**55**:629–31.
3. Eriksson AR, Albrektsson T. Temperature threshold levels for heat-induced bone tissue injury: a vital-microscopic study in the rabbit. *J Prosthet Dent* 1983;**50**:101–7.
4. Jung RE, Schneider D, Ganeles J, et al. Computer technology applications in surgical implant dentistry: a systematic review. *Int J Oral Maxillofac Implants* 2009;**24**(suppl):92–109.
5. Vercruyssen M, Laleman I, Jacobs R, Quirynen M. Computer-supported implant planning and guided surgery: a narrative review. *Clin Oral Implants Res* 2015;**26**(suppl 11):69–76.
6. Misir AF, Sumer M, Yenisey M, Ergioglu E. Effect of surgical drill guide on heat generated from implant drilling. *J Oral Maxillofac Surg* 2009;**67**:2663–8.
7. Jeong SM, Yoo JH, Fang Y, Choi BH, Son JS, Oh JH. The effect of guided flapless implant procedure on heat generation from implant drilling. *J Craniomaxillofac Surg* 2014;**42**:725–9.
8. Migliorati M, Amorfini L, Signori A, Barberis F, Silvestrini Biavati A, Benedicenti S. Internal bone temperature change during guided surgery preparations for dental implants: an in vitro study. *Int Oral Maxillofac Implants* 2013;**28**:1464–9.
9. dos Santos PL, Queiroz TP, Margonar R, et al. Evaluation of bone heating, drill deformation, and drill roughness after implant osteotomy: guided surgery and classic drilling procedure. *Int J Oral Maxillofac Implants* 2014;**29**:51–8.
10. Boa K, Varga Jr E, Pinter G, Csonka A, Gargyan I, Varga E. External cooling efficiently controls intraosseous temperature rise caused by drilling in a drilling guide system: an in vitro study. *Br J Oral Maxillofac Surg* 2015;**53**:973–7.
11. Lundskog J. Heat and bone tissue. An experimental investigation of the thermal properties of bone and threshold levels for thermal injury. *Scand J Plast Reconstr Surg* 1972;**9**:1–80.
12. Sener BC, Dergin G, Gursoy B, Kelesoglu E, Slih I. Effects of irrigation temperature on heat control in vitro at different drilling depths. *Clin Oral Implants Res* 2009;**20**:294–8.
13. Kondo S, Okada Y, Iseki H, et al. Thermological study of drilling bone tissue with a high-speed drill. *Neurosurgery* 2000;**46**:1162–8.
14. Davidson SR, James DF. Measurement of thermal conductivity of bovine cortical bone. *Med Eng Phys* 2000;**22**:741–7.
15. Yacker MJ, Klein M. The effect of irrigation on osteotomy depth and bur diameter. *Int J Oral Maxillofac Implants* 1996;**11**:634–8.
16. Katranji A, Misch K, Wang HL. Cortical bone thickness in dentate and edentulous human cadavers. *J Periodontol* 2007;**78**:874–8.
17. Augustin G, Davila S, Udiljak T, Vedrina DS, Bagatin D. Determination of spatial distribution of increase in bone temperature during drilling by infrared thermography: preliminary report. *Arch Orthop Trauma Surg* 2009;**129**:703–9.
18. Stelzle F, Frenkel C, Riemann M, Knipfer C, Stockmann P, Nkenke E. The effect of load on heat production, thermal effects and expenditure of time during implant site preparation - an experimental ex vivo comparison between piezosurgery and conventional drilling. *Clin Oral Implants Res* 2014;**25**:e140–8.
19. Sedlin ED, Hirsch C. Factors affecting the determination of the physical properties of femoral cortical bone. *Acta Orthop Scand* 1966;**37**:29–48.
20. Tehemar SH. Factors affecting heat generation during implant site preparation: A review of biologic observations and future considerations. *Int J Oral Maxillofac Implants* 1999;**14**:127–36.
21. Mohlhenrich SC, Modabber A, Steiner T, Mitchell DA, Holzle F. Heat generation and drill wear during dental implant site preparation: systematic review. *Br J Oral Maxillofac Surg* 2015;**53**:679–89.
22. Isler SC, Cansiz E, Tanyel C, Soluk M, Selvi F, Cebi Z. The effect of irrigation temperature on bone healing. *Int J Med Sci* 2011;**8**:704–8.