Intraosseous temperature rise due to template-guided and freehand surgical drilling with special attention to the role of cooled irrigation fluids in its control

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PhD thesis summary

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Introduction

The insertion of osseointegrated dental implants has become an everyday procedure. Besides research concerning optimal design, material, and surface modification, there is a growing interest among surgeons concerning precise preoperative planning and intraoperative placement of the implants. The availability of cone-beam computed tomography (CBCT) was the prerequisite for a rapid evolution in guided implant surgery, as it provided adequate imaging data with lower radiation. Jung et al. have divided guided systems into two main categories: dynamic systems and static systems. Dynamic systems use optical tracking technologies to follow the position of the handpiece as well as reference points of the bones and shows the projected path of implant placement on a virtual model of the bone, based on preoperative imaging. Static systems use preoperatively fabricated, patient-specific guides that are temporarily retained on either teeth or mucosa intraorally. Bone drilling is an everyday surgical procedure. Rotatory cutting results in friction, and consequent heat generation. Eriksson and Albrektsson have shown that an intraosseous temperature of 47°C for 1 minute is the threshold for the histological appearance of thermal osteonecrosis. Since the introduction of surgical guides in oral implantology, there was a concern among surgeons regarding the effectivity of irrigation during drilling, as it seems reasonable to doubt that the irrigation fluid reaches the drill bit the same way as it does in case of conventional freehand implant bed preparation.

Aims

Aims of investigation No. 1.

The aim of investigation No. 1. was to perform a pilot study that describes the importance of external cooling in guided surgical implant site preparation.

Aims of investigation No. 2.

Results of investigation No. 1. suggested that the question of intraosseous temperature rise in a guided setting should be studied in an experimental setup that controls more possible factors, such as axial load and the flow of external irrigation. As results of our research group in the new setting has shown that the use of 800 RPM drilling in such a setting is safe, the aim of investigation No. 2. was to perform a comprehensive assessment of the combination of the following factors: a) surgical method: guide vs. freehand drilling, b) drilling speed: 1200 vs. 1500 vs. 2000 RPM, c) temperature of the irrigation fluid: 10°C vs. 15°C vs. 20°C. Another important element of this experimental design was the elimination of the human factor in terms of axial load during drilling.

Materials and methods

Investigation No. 1.

Bone model. Drilling was performed on cortical bovine rib bones due to its thermophysical and anatomical properties, as well as to its good availability and easy handling. The ribs were derived from the same animal and were frozen to -10°C in saline solution when not used. Before the measurements took place, the specimens were warmed to 36±1°C. Flat parts of the bovine ribs were divided and cut into segments as long as attachment of the surgical guide containing 3x8 drilling holes to it was possible. After that, the edges were cut from the ribs in a longitudinal fashion, followed by cutting the specimens into two halves through its cancellous bone layer, parallel to the flat surface of the bone. This was followed by the removal of the remaining cancellous bone tissue with a chisel. Thus, we could prepare quasi flat bone specimens containing only the cortical layer.

Setup. Heat measurement was performed with an infrared thermometric device (Voltcraft IR-380, Conrad, Germany). As the specimens were flat cortical parts of the bovine ribs, a universal surgical guide was designed containing 24 guiding canals in 3 columns. The guide was manufactured using the same standards as the guides of the Smart Guide system (Smart Dental Solutions Ltd., Szeged, Hungary), 3D printed (printer: ProJet 3510 MP), using the same material (VisiJet Stoneplast). Fixation was available by inserting the system's standard pins into pin holes placed in the four corners. Drilling was performed by the same experienced dentoalveolar surgeon in order to achieve quasi constant applied pressure. Slight pumping drilling motion to facilitate the transfer of the heated debris from the canal was applied. The surgeon was not able to see the screen of the thermometer; thus, it was not affecting his usual drilling motion and the pressure applied by him. Drill speed was set to a constant 800 RPM as it is advised by the manual of the Smart Guide system used in this study. Every step of the drilling sequence was investigated. The applied implant preparation system includes the subsequent use of drills of the following diameters: 2.0 mm, 2.5 mm, 3.0 mm, and 3.5 mm. External cooling was applied by the assistant with a standard 50 ml syringe at the point of the drill entering the metal sleeve of the canal in the drilling guide. Standard saline solution at a room temperature of 25°C was used as coolant liquid. The drills were washed and cooled back to room temperature after every single drilling.

Collection of data and statistical analysis. Baseline and peak temperatures were collected to one decimal point in a spreadsheet file Microsoft Excel 2013 (v15.0) (Microsoft Corporation, Redmond, WA, USA). Temperature elevations were calculated as peak temperature minus baseline temperature to one decimal point using the spreadsheet. After converting the dataset of temperature elevations to a comma separated values file, it was statistically analysed using RStudio (RStudio Inc., Boston, MA, USA) software. Two sample t-test was computed in case of similar variances of the two compared groups, and Welch's t-test was used in case of differing variances. The level of significance was set a priori at $\alpha=0.05$.

Investigation No. 2.

Bone model. The bone model used in the presented investigation was bovine rib bone, as several available data suggest that it is ideal for in vitro experiments in oral implantology. The bone segments used during our experiments were deriving from the same animal. The animal was not sacrificed in order to perform our investigations. Storage of the bone segments when not used was following the protocol established by Sedlin and Hirsch: in standard saline solution, at a temperature of -10°C.

Setup. The study was designed to investigate both guided and freehand implant bed preparation techniques. In case of the guided surgical drilling group, drillings were conducted using a 3D-printed surgical guide that fit well on the quasi-flat surface of the specimens. The guide was designed using the same principles and protocols as in case of every surgical guide of a commercially available implantological guide system (SmartGuide, dicomLAB Kft., Szeged, Hungary), and contained 2x5 guiding canals with a metal insert, and was able to accommodate the metal guiding spoons that are designed to guide the drill bits of different diameters. The guide was designed in a fashion that allowed a thermocouple to be placed in close proximity to the canal to be drilled. Measurement beds were placed right at the point where the guiding canal of the guide reaches the bone surface, using another 3D-printed guide for precision. In case of freehand surgical drillings, the entry points were marked on the bone surface using the same guides as in case of the guided surgical groups, but the guides were removed. Measurement beds for freehand drillings were placed using the same guides as in case of the guided subgroups. All measurement beds were prepared with a depth control of 1.8 mm to ensure that they are still in the cortical layer of the bone, as a study investigating heat distribution during drilling confirmed that peak temperature during drilling develops in the cortical layer of the bone. After placing the thermocouple inside the bed, it was tightly filled with cortical bone chips of the same animal, and the bed was insulated with plasticine to avoid any direct contact with the irrigation solution, that might influence the measurements. The measurement beds were in the following distance from the canal to be drilled: 1.0 mm when using the 3.5 mm drill bits, 1.25 mm when using the 3.0 mm drill bits, 1.50 mm when using the 2.5 mm drill bits, and 1.75 mm when using the 2.0 mm drill bits. K-type thermocouples were used for the measurements and were connected to a measurement device (Holdpeak-885A, Holdpeak, China). The bone specimens were carefully warmed to a value around body temperature (37±1°C). The temperature elevations were calculated by subtracting the baseline temperature from the peak temperature measured. Osteotomies were performed in a regular fashion with the drill passing through the cortical layer of the bone down into cancellous bone. The drillings were terminated when the continuously measured cortical temperature reached its peak and did not show any further tendency to elevate, thus the time factor was not investigated in the experiment. A bench drill (Bosch PBD 40, Bosch, Germany) was used for the experiments. The axial pressure was controlled at a level of 2.0 kg, as it can be considered as a light hand pressure exerted during implant site preparation. External irrigation was conducted using a widely used surgical unit (W&H Implantmed SI-923, W&H, Austria) and a widely used, standard cannula (W&H, Austria). The flow was 105 mL/min. Normal saline was used as an irrigation solution. The irrigation fluids were used on three different pre-set temperatures: 10°C, 15°C, and 20°C. The measurements and drillings were only initiated if the temperature of the fluid was around the wanted pre-set value (±1°C). In case of 2.5 mm, 3.0 mm, and 3.5 mm drillings, the canals were predrilled with 2.0 mm, 2.5 mm, 3.0 mm drills respectively.

Collection of data and statistical analysis. Baseline and peak temperatures were collected to one decimal point in a spreadsheet file using Microsoft Excel 2013 (v15.0) (Microsoft Corporation, Redmond, WA, USA). Temperature elevations were calculated as peak temperature minus baseline temperature to one decimal point using the spreadsheet. The values were statistically analysed using Statistica for Windows 10.0 (Statsoft, Tulsa, OK, USA). Normality of distributions was tested using Shapiro-Wilk test. One-way ANOVA with post-hoc Tukey HSD test was planned to be used in case of normal distributions, and Kruskal-Wallis ANOVA was planned to be used if non-normal distribution was detected.

Results

Investigation No. 1.

The first step of the implant system's drilling sequence is drilling with the 2.0 mm pilot drill. 48 drillings performed with the use of external irrigation produced a mean temperature rise of 4.77°C, while in case of 48 drillings performed without the use of external cooling it was 7.02°C. The difference was statistically significant ($p<0.001$). Eight times out of the 48 drillings performed did the rise exceed the 10°C threshold on the latter case, while no drilling exceeded it if external cooling was applied. During the second step of the drilling sequence (being 2.5 mm drilling of the 2.0 mm canal) the mean temperature rise was 5.22°C with cooling, and 8.48°C without cooling. The difference was statistically significant ($p<0.001$). Number of measured temperature rises exceeding the threshold was 1 out of 48 with cooling and 17 out of 48 without cooling. Throughout the third step of the drilling sequence (being 3.0 mm drilling of the 2.5 mm canal) the mean temperature rise was 3.32°C with cooling, and 8.48°C without cooling. The difference was statistically significant ($p<0.001$). No cases out 48 drillings exceeded the threshold for temperature rise with the use of external irrigation, while without the use of it 18 times out of the 24 performed drilling was the increase exceeding the limit. During the fourth step of the drilling sequence (being 3.5 mm drilling of the 3.0 mm canal) the mean temperature rise was 4.75°C if external cooling was applied, and 9.40°C if no external cooling was applied. The difference was statistically significant ($p<0.001$). Number of measured temperature rises exceeding the threshold was 0 out of 24 with cooling and 10 out of 24 without cooling.

Investigation No. 2.

Results for the 1200 RPM drilling groups can be summarized as the following: 1) 1200 RPM freehand drilling with 10°C irrigation yielded a significantly lower temperature increment as compared to the 20°C guided group, regardless of the diameter of the drill. 2) When comparing freehand drilling with 10°C irrigation to freehand drilling with 20°C irrigation, a significant difference can be observed between groups with the same drill diameter, with the exception of 3.5 mm drill diameter groups. 3) When 10°C freehand irrigation was compared with 15°C freehand irrigation, the difference was significant at 2.5 and 3.0 mm, indicating the superior efficiency of lower temperature irrigation. 4) Guided 1200 RPM drilling with 10°C irrigation yielded a significantly lower temperature increment as compared to the 20°C guided group, regardless of the diameter of the drill. 5) When compared to the 20 °C freehand group, temperature reduction in the 10°C guided group was significantly more marked at all diameters, except for 3.5 mm. 6) When the 10 °C guided group was compared to the 15 °C groups, a significantly lower temperature rise was found at 2.5 and 3.0 mm in comparison to the guided technique, and at 3.0 mm in comparison to the freehand technique.

Results of the 1500 RPM drilling group can be summarized as the following: 1) Guided 1500 RPM drilling with irrigation fluid at 20°C produced values exceeding the 10°C limit in case of the 3.0 and 3.5 mm drill bit diameters, with the mean exceeding 11.0°C in case of the 3.5 mm diameter. 2) Freehand drilling with 20°C irrigation produced no values to exceed 8.8°C, and the means to stay below 8.0°C for all diameters. 3) The mean freehand values were significantly lower compared to guided drilling with irrigation at 20°C at the 3.0 mm ($p=0.000$) and the 3.5 mm ($p=0.000$) diameters. 4) The use of 15°C irrigation managed to hold the mean temperature elevation below 8.0°C at the diameter of 3.5 mm for both guided (a mean of 7.6°C) and freehand (a mean of 7.3°C) surgery. 5) When using 15°C irrigation, no statistically significant difference was detectable between the two methods, with the exception of the 3.0 mm diameter, where guided surgery produced significantly higher values ($p=0.032$). 6) With the use of 10°C irrigation, every mean value was below 6.0°C and no single measured value exceeded 7.1°C. 7) The use of 10°C irrigation managed to completely erase every statistically significant difference between the two surgical methods.

Results of the 2000 RPM drilling group can be summarized as the following: 1) For the 20°C irrigation guided drilling groups, the means exceeded the limit in case of the 3.0 and 3.5 mm guided, and the 3.5 mm freehand groups. 2) Moreover, for guided drillings with 20°C irrigation, the maximum values reached 13.0°C in case of 2.5 and 3.0 mm, and 16.0°C in case of the 3.5 mm groups. 3) Guided drillings with 20°C irrigation produced significantly higher values of temperature elevation compared to the freehand groups at all diameters (2.0 mm ($p=0.039$), 2.5 mm ($p=0.001$), 3.0 mm ($p=0.047$) and 3.5 mm ($p=0.000$)). 4) The means exceeded the limit in case of guided 3.0 and 3.5 mm drilling groups with 15°C irrigation. 5) Freehand drillings with 15°C irrigation remained in the safe zone for all diameters. 6) When using 15°C irrigation, guided drillings were shown to produce significantly higher temperature changes compared to freehand drillings at the 2.0 mm ($p=0.000$), 3.0 mm ($p=0.000$) and the 3.5 mm ($p=0.000$) diameters. 7) No means exceeded 7.0°C, and no single measurement showed an elevation exceeding 8.9°C when 10°C irrigation was used. 8) When using 10°C irrigation fluid, no significant difference was detectable between guided and freehand drilling.

Discussion

Our presented results confirm that the use of prefabricated drilling guides during implant site preparation results in a higher temperature rise when compared to that of the freehand method, however, the use of 1200 RPM is still a safe choice. Higher drilling speeds of 1500 and 2000 RPM have also been investigated in our study. The above presented results show that the use of these higher drilling speeds results in critical temperature elevations in a guided setting, and only the use of irrigation fluid pre-cooled to 10°C can hold the increment in the safe zone. Moreover, the use of 2000 RPM produces critical elevations in a freehand setting as well, while in case of 1500 RPM freehand drillings, the elevations stay somewhat below the threshold.

Considering the fact that axial pressure was controlled in the presented setup, and other local factors can influence the temperature elevation as well, we can suggest that the use of 1500 and 2000 RPM drilling should be avoided if possible.

Conclusions

New findings of the investigations can be summarized as the following: 1) According to the presented data, guided surgery using a drilling speed of 1200 RPM can be safe in terms of intraosseous temperature rise. 2) Our results suggest that 1500 and 2000 RPM drilling combined with the use of irrigation fluid at a temperature of 20°C might result in critical temperature elevations, thus, the use of these higher drilling speeds in implant site preparation should be avoided. If the clinical situation requires the use of these higher drilling speeds, irrigation with an irrigation fluid cooled to 10°C is advisable. 3) We can conclude that according to our data, the safe choice for guided implant placement is the combination of a lower drilling speed of 800 or 1200 RPM drilling and the use of a cooled irrigation fluid.

Publications providing the basis of the thesis

I. **Boa K**, Varga E Jr, 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. British Journal of Oral & Maxillofacial Surgery, 2015; 53(10):963-967. IF_{2015}: 1.237

II. **Boa K**, Barrak I, Varga E Jr, Joob-Fancsaly A, Varga E, Piffko J. Intraosseous generation of heat during guided surgical drilling: an ex vivo study of the effect of the temperature of the irrigating fluid. British Journal of Oral & Maxillofacial Surgery, 2016; 54(8):904-908. IF_{2016}: 1.218

III. Barrak I, **Boa K**, Joob-Fancsaly A, Sculean A, Piffko J. Heat generation during guided and freehand implant site preparation at drilling speeds of 1500 and 2000 RPM: an in vitro study (Accepted for publication with revisions in Oral Health and Preventive Dentistry)

Other publications

- Barrak I, Joób-Fancsaly Á, Braunitzer G, Varga E Jr, **Boa K**, Piffkó J. Intraosseous heat generation during osteotomy performed freehand and through template with an integrated metal guide sleeve: an in vitro study. Implant Dentistry, 2018; 27(3):342-350. IF_{2017}: 1.307

- Barrak I, Joób-Fancsaly A, Varga E, **Boa K**, Piffko J. Effect of the combination of low-speed drilling and cooled irrigation fluid on intraosseous heat generation during guided surgical implant site preparation: an in vitro study. Implant Dentistry, 2017; 26(4):541-546. IF_{2017}: 1.307
- Csonka A, Sikarinkul E, Gargyan I, **Boa K**, Varga E. Operative management of bilateral Salter-Harris type III fractures of the proximal phalanges of the great toes of a 10-year-old female ballet dancer: a case report. Journal of Pediatric Orthopaedics B, 2016; 25(4):393-396. IF_{2016}: 0.638
- Csonka A, Gargyan I, **Boa K**, Sadt Z, Varga E. *Bicondylaris tibia plató törések kettős lemezelése*. [Double plating of bicondylar tibial plateau fractures.] Magyar Traumatológia, Ortopédia, Kézsebészet, Plasztikai Sebészet, 2016; 59(3-4): 99-105.
- Csonka A, Gargyan I, Borondy J, **Boa K**, Varga E. *Megoldást jelent-e a szögstabil implantátumok bevezetése a proximalis humerus törések ellátásában?* [Are angular stable implants suitable for the treatment of proximal humerus fractures?] Magyar Traumatológia, Ortopédia, Kézsebészet, Plasztikai Sebészet, 2016; 59(3-4): 107-112.

- Varga E, Csonka E, Kószó B, Pető Z, Ágoston Z, Gyura E, Nardai G, **Boa K**, Süveges G. Advanced Trauma Life Support (ATLS) in Hungary; The First 10 Years. Bulletin of Emergency and Trauma, 2016; 4(1):48-50.
- **Boa K**, Pintér G, Varga E Jr., Erdohelyi B, Varga E *Fúrás által okozott intraossealis hőmérséklet-emelkedés nagyszámú csontfúrás után: in vitro vizsgálataink eredménye*. [Intraosseous temperature rise due to drilling after excessive number of drillings: results of our in vitro investigations.] Biomechanica Hungarica, 2015; 8(1):28.
- Gargyan I, Vagi Zs, Csonka A, **Boa K**, Varga E. *ß-tricalcium phosphate granulátum alkalmazása a tibia plató törések kezelésében*. [Administration of ß–tricalcium phosphate granulate in the treatment of tibial plateau fractures.] Magyar Traumatológia, Ortopédia, Kézsebészet, Plasztikai Sebészet, 2015; 58(4):201-207.
- Gargyan I, Csonka A, **Boa K**, Kormondi S, Toth K, Varga E. *Periprotetikus distalis femurtörések minimál invazív lemezes rögzítése totál térdprotézis beültetése után*. [Minimally invasive plate osteosynthesis of distal periprosthetic femoral fractures after total knee replacement.] Magyar Traumatológia, Ortopédia, Kézsebészet, Plasztikai Sebészet, 2015; 58(4):209-216.

- Gargyan I, Csonka A, **Boa K**, Varga E. Complex treatment of complicated crural decollement injury in a diabetic patient. European Journal of Trauma and Emergency Surgery, 2015; 41(Suppl. 2):S182.