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Thermal changes and drill wear in bovine bone during implant site preparation. A comparative *in vitro* study: twisted stainless steel and ceramic drills

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Abstract

Objectives: The purpose was to assess thermal changes and drill wear in bovine bone tissue with the use of twisted stainless steel and zirconia-based drills, during implant site preparation.

Methods: A total of 100 implant site preparations were performed on bovine ribs using a surgical unit linked to a testing device, in order to standardize/simulate implant drilling procedures. Bone temperature variations and drilling force were recorded when drilling at a depth of 8 and 10 mm. A constant irrigation of 50 ml/min. (21 ± 1°C) and drilling speed of 800 r.p.m. were used. Scanning electron microscopy analysis was preformed prior and after drilling.

Results: Mean temperature increase with both drills at 8 mm was 0.9°C and at 10 mm was 2°C ($P<0.0001$). Statistical significant higher bone temperatures were obtained with stainless steel drill (1.6°C), when comparing with the ceramic drill (1.3°C) ($P<0.05$). Temperature increase was correlated with higher number of perforations ($P<0.05$) and drilling load applied. There was no significant association between drilling force applied and temperature increase by either drill or at either depth. No severe signs of wear of either drill were detected after 50 uses.

Conclusions: Drill material and design, number of uses, depth and drilling load applied appear to influence bone temperature variations during implant site preparation. Drilling depth was a predominant factor in bone temperature increase. Both drills can be used up to 50 times without producing harmful temperatures to bone tissue or severe signs of wear and deformation.

Implant success and survival depend largely on the achievement of adequate healing and the establishment of a correct osseointegration process (Albrektsson et al. 1981). Thermal damage at the drilling site inhibits bone regeneration leading to hyperaemia, fibrosis, osteocyte degeneration, increased osteoclastic activity and necrosis, consequently being a major factor influencing implant survival (Brisman 1996; Kerawala, et al. 1999; Harris & Kohles 2001; Sener et al. 2009). Hence, the importance of minimizing thermal and mechanical injury during the drilling sequence (Sharawy et al. 2002; Ercoli et al. 2004). But even when a precise drilling technique is applied, most of the energy used in the cutting process is dissipated into heat, especially after increased wear (Ercoli et al. 2004; Allan, et al. 2005; Chacon, et al. 2006). Eriksson, Albrektsson and colleagues determined that the upper threshold for bone survival during implant preparation ranged between 44°C and 47°C, when drilling time was kept below 1 min, while at 50°C the regenerative capacity of the bone was practically inexistent (Eriksson & Albrektsson 1983, 1985; Eriksson & Adell 1986). And that even seconds of bone exposure to temperatures around 90°C were sufficient to induce bone necrosis (Eriksson et al. 1984a, 1984b). Many other studies had similar results, nevertheless the exact temperature limier due to overheating is still unknown. Consequently temperatures above 50°C are widely accepted to promote thermonecrosis (Bachus et al. 2000). This fact is based on knowledge that at temperatures of 56°C the bone alkaline phosphatase (ALP) is denatured (Benington et al. 1996; Tehemar 1999). Furthermore, at temperatures below ALP denaturation point (47°C and 48°C), tissue lesion may occur due to the burning and resorption of fat cells and reduction of blood flow (Harder et al. 2009).

During implant site preparation, the amount of heat depends on multiple factors, such as: drills sharpness, design and diameter, applied force, drilling speed and depth, duration and cutting motion (continuous vs. intermittent), as well as bone density and irrigation (Sutter et al. 1992;

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Yacker & Klein 1996; Iyer et al. 1997; Reingewirtz et al. 1997; Tehemar 1999; Sharawy et al. 2002; Ercoli et al. 2004; Chacon et al. 2006). Drill design, material and excessive use in addition to disinfection and sterilization processes can also lead to drill wear, producing higher frictional heat (Ercoli et al. 2004; Chacon et al. 2006); however, its impact on heat generation during implant site preparation remains unclear.

At present, implant drills are made of stainless-steel alloys, stainless steel coated with titanium nitride and, recently, oxide zirconia (Zr)-based ceramic.

The combination of oxide of Zr with yitrium, magnesium or alumina (Al) permits the stabilization of Zr, providing better biomechanical properties. These high performance mixed ceramic drills are mainly composed of 80% zirconia oxide and 20% alumina oxide, presenting thermal stability, low thermal conductivity, and higher resistance to fracture and wear and with an elastic modulus similar to steel (Piconi & Maccauro 1999; Bayerlein et al. 2006; Scarano et al. 2007).

The scientific evidence related to the use ceramic drills in implantology is scarce and based solely on microscopic findings of wear after several uses (Bayerlein et al. 2006; Scarano et al. 2007). Although material wear and durability are important, the possibility that ceramic drills may reduce thermal heat during implant site preparation, after several uses, is of higher clinical relevance as it may directly affect implant survival and success. This study aims to asses thermal changes in bovine bone tissue with the use of twisted stainless steel and Zr-based drills, during implant site preparation.

Material and methods

Bone specimen preparation

Twelve bovine bone ribs were used in this study, because of the similarities between bovine bone and human mandibular bone in terms of density and relationship between cortical and cancellous bone (Eriksson & Adell 1986; Yacker & Klein 1996; Ercoli et al. 2004). The samples were cleaned and removed of all soft tissue residues, then immersed in a saline and ethanol solution (1 : 1), according to the methodology described by Tricio et al. (1995). In order to minimize changes in bone thermophysical and mechanical proprieties, the specimens were frozen in sterile saline solution at −10°C, according to previous publications (Sedlin & Hirsch 1966; Tricio et al. 1995; Harder et al. 2009). Before implant site preparation bone specimens were maintained at room temperature (± 21°C) for 3 h, wrapped with saline-soaked gauze for hydration. Subsequently the ribs were sawed into bone blocks approximately 70 mm in length. Each rib was divided in two to three portions and only the samples with a minimum height of 12 mm were selected. The remaining unfrozen blocks were maintained refrigerated in saline solution until use, during a 24 h period.

Experimental set-up

The mechanical device designed for this specific experiment was composed of a multiphase motor with a reductor that allowed a controlled speed of dislocation of the handpiece (feed-rate) of 57 mm/s, and a load cell with a instant reading in kilogram and a precision of ± 0.02 g. The thermometer used to control the temperature was an HIBOK 14 (Wika Lda., Taoyuan, Taiwan) with a reading range between 0°C and 260 ± 0.1°C, with a type K thermocouple. The thermocouple was calibrated against traceable standards (5°C and 55°C) before each perforation. The perforations were made with the same Bienair® handpiece (Le Noirmont, Switzerland) and motor during the entire procedure. Experimental set-up is reported in Fig. 1.

Experimental protocol

Each prepared bone specimen was placed in condensation silicone (Labosil®, Protechno SA, Girona, Spain) and fixed to a table with three pins. Bone specimens were kept in place until the completion of the drilling sequence, which was only started following the setting of the silicone and normalization of the temperature inside the specimen (± 21°C). Bone specimen movement, for further perforations (6 mm apart) and for the thermocouple placement (1.5 mm from perforation) were obtained with precise predefined dislocation of the table (Fig. 2). The thermocouple hole was made with a 1 mm diameter round spherical bur at a depth of 8 mm from the cortical surface, previously marked using an endodontic ruler. The thermocouple probe, properly calibrated and marked at 8 mm, was then placed in the prepared site and sealed from irrigation with blue wax, presenting a response time of 3 s and allowing the determination of the bone baseline temperature. The table was then repositioned at the defined drilling location (1.5 mm from the thermocouple), in order to obtain precise parallelism. The first perforation was carried out with a twisted stainless steel drill ∅2 × 19 mm (MIS®, Tel Aviv, Israel), at the standardized depths of 8 and 10 mm. Followed by the ceramic twisted drill of ∅2 × 19 mm (MIS®), in order to reduce any bias due to different densities of the bone specimens. Each specimen was perforated ten times (five times with each drill) (Fig. 3). To simulate progressive and intermittent perforation,

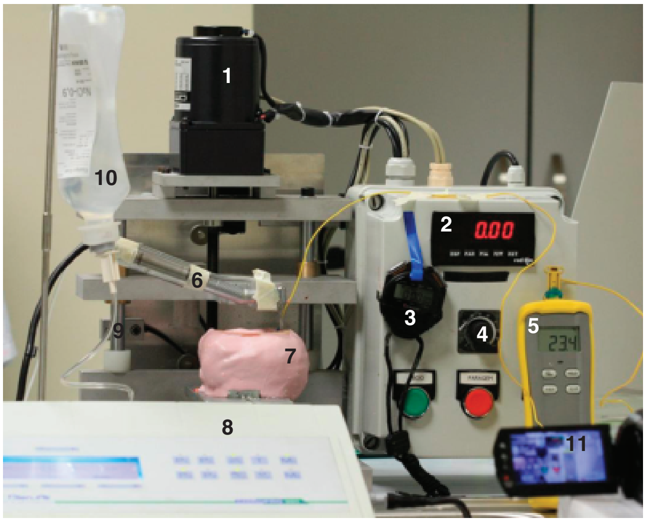

Fig. 1. Experimental set-up: 1, motor; 2, load cell display; 3, chronometer; 4, motor velocity regulator; 5, thermocouple with type K thermopar; 6, handpiece (Bienair®); 7, Labosil® speciemen stabilization; 8, Bienair® implant motor; 9, magnetic sensor; 10, saline solution; 11, video camera.

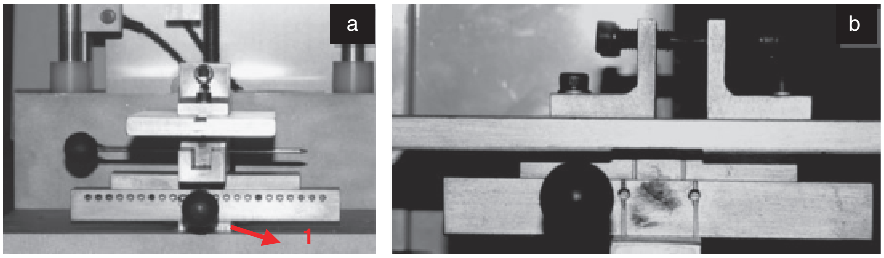

Fig. 2. Table with predetermined holes for precise specimen dislocation: (a) movement between site preparations (6 in 6 mm) 1, load cell; (b) movement between thermocouple and site preparation (1.5 mm).

drill entry and removal was activated with magnetic sensors when the depths were achieved, thus seeking to reproduce daily clinical protocol. The drilling protocol was carried out with a constant dislocation of the handpiece (57 mm/min) and a constant rotational speed of 800 r.p.m. Irrigation was also constant, with a perfusion of 50 ml/min of saline solution at room temperature (21 ± 1°C). The maximum force exercised during perforation was variable and registered when 8 and 10 mm of depth were attained. The temperature was recorded at 8 and 10 mm depth, in each perforation, until 50 cycles were completed. During the calibration of the thermocouple and the change of the drills the bone sample was maintained at room temperature and hydrated at all times (humid gauzes with saline solution).

Scanning electron microscopy (SEM) and EDAX analysis

Quantitative energy-dispersive X-ray spectroscopy (EDX) analysis was performed with a new stainless steel and ceramic drills, to assess their chemical composition with an acceleration voltage of 25 Kv.

Additionally, SEM analysis, with a scanning electron microscopy-field emission gun (model JEOL JSM-7001F, JEOL Electron Microscopy model JSM-7001F, Tokyo, Japan), was conducted previously and following the establishment of 50 perforations by both drills, in order to asses drill wear.

Data recollection

Before every implant site preparation the load cell was tared, the thermocouple was calibrated, room temperature and bone baseline temperature were recorded.

During each intermittent drilling the maximum bone temperature and maximum applied force were registered at a depth of 8 and 10 mm, respectively. The total time of each perforation was controlled with a chronometer during every site preparation. All perforations were controlled by the same operator and data was obtained from video records of each perforation. An Excel sheet for each drill was then filled with the following information: room temperature, specimen baseline temperature, maximum drilling temperatures at 8 and 10 mm, maximum drilling force applied until 8 and until 10 mm, temperature variation and final time of perforation. The variation of temperature in each perforation was calculated by subtracting the obtained temperature (at 8 mm- T_8 and 10 mm- T_{10}) with the bone specimen baseline temperature (T_0) before each perforation

$$\Delta T(^\circ\mathrm{C}) = (T_8 \text{ or } T_{10}) - T_0$$

Subsequently, Stragraphics 5.1 was used to statistically compare the recollected data between both types of drills.

Results

Temperature variations

Mean baseline bone temperature for the stainless steel and ceramic drills were 21.59 ± 0.1°C and 21.6 ± 0.1°C, respectively. The mean time of drilling was similar, 31 and 32 s, being slightly longer for the stainless steel drill.

(a) *Temperature and depth*: There were statistically significant differences between temperature increase at 8 and 10 mm depth, when perforating with both drills (ANOVA $P < 0.0001$). The mean temperature increase was 0.92 ± 0.78°C at 8 mm and 2.07 ± 1.14°C at 10 mm (Figs 4 and 5).

(b) *Temperature and drill*: There were statistically significant differences in temperature increase when comparing the ceramic with stainless steel drill (ANOVA $P < 0.05$). The mean increase in temperature at both depths until 50 uses, was 1.35 ± 1.15°C for the ceramic drill and 1.64 ± 1.11°C for the stainless steel drill (Figs 4 and 5).

(c) *Temperature variations according to drilling depth with each drill*: The lower mean temperatures registered were with the ceramic drill whilst drilling at 8 mm (0.79 ± 0.76°C) and the higher mean temperatures were produced with the stainless steel drill at 10 mm (2.24 ± 1.1°C). At both depths, the ceramic drill induced less overall bone temperature increase (Figs 4 and 5).

(d) *Temperature and drill uses*: A positive correlation was found between temperature increase and the number of perforations for both stainless steel (Spearman's $P \leq 0.01$; $r = 0.32$) and

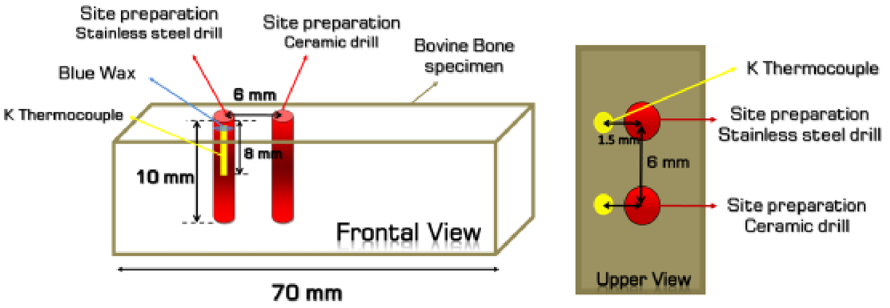

Fig. 3. Schematic representation of bone specimen, thermocouple positioning and implant site preparation distribution and sequence (each sample was perforated 10 times, five times with each drill).

Comparison of Temperature with:		Mean	SD	Analysis	P-valor
Depth	8mm	0.92 °C	± 0.78°C	ANOVA two factors	< 0,0001
	10mm	2.07 °C	± 1.14°C		
Drill	Steel drill	1.64 °C	± 1.11°C	ANOVA two factors	0.035
	Ceramic drill	1.35 °C	± 1.15°C		
Interaction Drill and Depth	Steel drill 8 mm	1.04 °C	± 0.8°C	ANOVA two factors	0.7268
	Steel drill 10 mm	2.24 °C	± 1.1°C		
	Ceramic drill 8mm	0,79 °C	± 0.7°C		
	Ceramic drill 10mm	1.90 °C	± 1.2°C		

Fig. 4. Statistic analysis used to compare temperature increase with drilling depth and drill type.

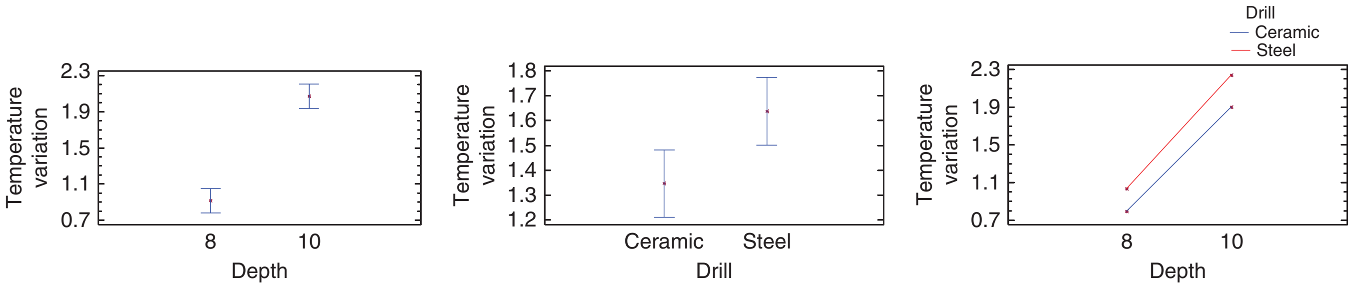

Fig. 5. Mean temperature increase variations according to depth and drill used during implant site preparations.

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ceramic drills (Spearman's $P \leq 0.01$; $r = 0.25$). (Fig. 6)

(e) *Temperature and drilling load*: The correlation between temperature increase and applied load, during drilling at either depths were statistically significant (Spearman's $P \leq 0.001$) (Fig. 6).

Drilling load

When comparing the drilling force (kg) applied by the mechanical device to perform the perforations, there were significant differences between the two drills used, at either depths (ANOVA $P < 0.05$) (Fig. 9). The mean loads applied during implant site preparation were 1.59 ± 0.6 kg at 8 mm and 1.34 ± 0.8 kg at 10 mm (Figs 9 and 10). When comparing the ceramic and stainless steel drill, the respective loads of 1.65 ± 0.7 and 1.28 ± 0.7 kg (Figs 7 and 8). The lower drilling forces were used when drilling with the ceramic dill at 10 mm and the higher with the stainless steel drill at 8 mm.

SEM and EDX analysis

SEM analysis revealed in detail the morphology and design of the drills, reporting small differences. Additionally, signs of machination were visible at the tip of the new stainless steel drill surface (Fig. 9). Such alterations were not observed with the ceramic drill.

When comparing SEM images of both drills before and following 50 uses, it is possible to identify different patterns of wear. The ceramic drill had slightly visible alterations on one of the sides the drill tip, contrasting with the stainless steel drill, which showed higher tip wear in both edges. However, none of the drills appeared to present severe deformation or blunting after 50 uses. The visible derbies, in the SEM images, are most likely bone residue as no active cleaning or sterilization was performed, apart from soft rinsing with water (Fig. 10).

The EDX analysis identified the main constituents of the stainless steel alloy drill as iron, chromium and nickel. The main components of the ceramic drill were Zr, Al, oxides (O) and carbon (Fig. 11).

Discussion

In this study, the mean temperature increases recorded during drilling was always above baseline bone temperature and below the critical harmful threshold. This showed that the external irrigation, at a rate of 50 ml/min, and the drilling methodology protocol employed, were sufficiently effective to suppress excessive bone heating with both drills, up to 50 implant site preparations (Yacker & Klein 1996; Jochum & Reichart 2000; Chacon et al. 2006). Also, the mean temperatures rise recorded at 8 and 10 mm were significantly different, indicating depth as factor influencing heat generation during implant site preparation, as indicated by other authors (Cordioli & Majzoub 1997; Misir et al. 2009; Sener et al. 2009).This fact may be influenced by inability of a correct irrigation solution at higher depths (Kerawala et al. 1999).

Drill design and material composition (ceramic and stainless steel) had a statistic significant influence on the overall recorded temperature increase, indicating that with the same standardized drilling protocol, ceramic drills induced less bone heat after 50 implant site preparations. This may be a result of a higher resistance to wear, as observed in the SEM images. Despite the inexistence of literature related to temperature increase with ceramic drills, a statistical difference of 0.3°C, should not be considered as clinically significant value, as it will not lead to substantial lower risk of thermonecrosis. However, the impact of drill design in published studies is controversial (Watanabe et al. 1992; Cordioli & Majzoub 1997; Benington et al. 1996; Iyer et al. 1997; Ercoli et al. 2004).

Bone temperature increase seemed to be affected by the loss of drill sharpness with both drills due to multiple uses, even without the submission to any disinfection or sterilization process (Matthews & Hirsch 1972). Jochum and Reichart (2000) concluded that to detect significant temperature changes, drills had to be used up to 40 times. Misir et al. (2009) detected temperature increase of 4°C and 10°C after 35 and 45 uses, respectively, however, a continuous drilling was preformed, with a constant drilling load of 2 kg and a speed of 1500 r.p.m. Attending that the manufacture only recommends the usage of the stainless steel drill up to 30 times, the reported protocol was conducted with 50 uses, with similar results to those reported in the literature (Jochum & Reichart 2000; Ercoli et al. 2004).

Correlation of Temperature with:		Analysis	Correlation coefficient	P-valor
Nº of uses	Steel drill	Spearman	0,3163	0,0017
	Ceramic drill	Spearman	0,2473	0,0139
Drilling load	8mm depth	Spearman	0,3928	0.0001
	10mm depth	Spearman	0.7034	0,0001

Fig. 6. Statistic analysis of the effect of the number of uses and drilling load on temperature.

Comparison of Drilling load with:		Mean	SD	Analysis	P-valor
Depth	8mm	1.59 Kg	± 0.6 Kg	ANOVA two factors	0.0129
	10mm	1.34 Kg	± 0.8 Kg		
Drill	Steel drill	1.65 Kg	± 0.7 Kg	ANOVA two factors	0.0004
	Ceramic drill	1.28 Kg	± 0.7 Kg		
Interaction Drill and Depth	Steel drill 8 mm	1.83 Kg	± 0.5 Kg	ANOVA two factors	0.3176
	Steel drill 10 mm	1.47 Kg	± 0.8 Kg		
	Ceramic drill 8mm	1.36 Kg	± 0.7 Kg		
	Ceramic drill 10mm	1.20 Kg	± 0.9 Kg		

Fig. 7. Statistic analysis used to compare drilling load applied according to depth and drill used.

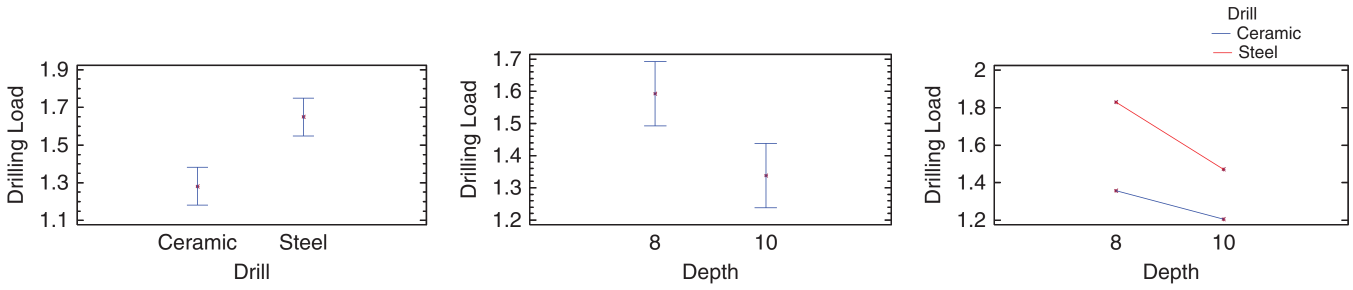

Fig. 8. Mean drilling loads applied during implant site preparations at both depths and with each drill.

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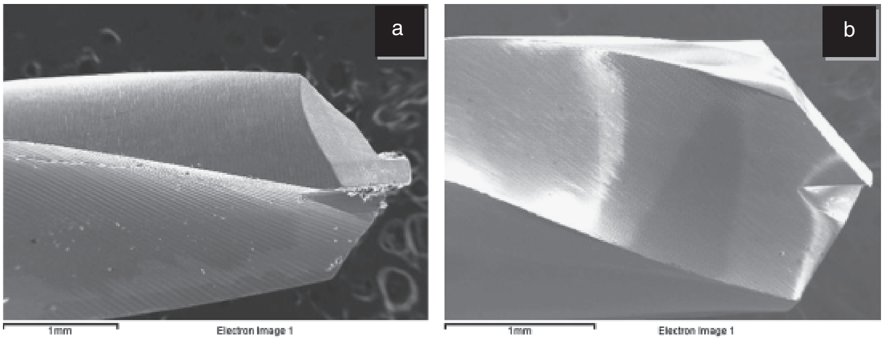

Fig. 9. SEM analysis of new drills stainless steel (a) and ceramic (b) drills.

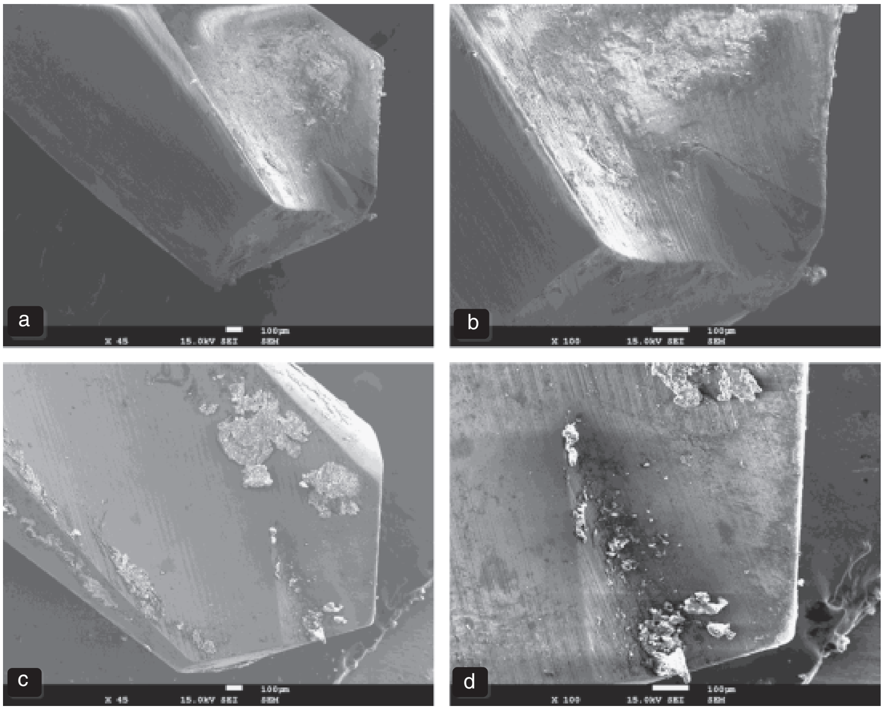

Fig. 10. SEM analysis of ceramic drill (a and b) and stainless steel drill (c and d), after 50 uses; with different amplifications, × 45 (a and c) and × 100 (b and d).

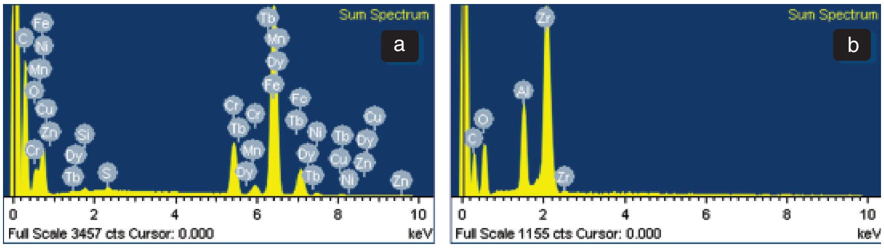

Fig. 11. EDX analysis results of new stainless steel (a) and ceramic (b) drills.

In relation to the force applied during drilling, most *in vitro* studies apply constant loads by the use of a pneumatic system or with the simple application of weights (Abouzgia & James 1996, 1997; Bachus et al. 2000; Benington et al. 2002; Chacon et al. 2006), providing a continuous drilling, that does not correspond to the clinical drilling protocol and which may influence bone temperature readings. With this protocol, the forces applied during drilling were a relevant factor in heat production (Brisman et al. 1996). Tehemar et al. (1999) recommended, low pressures in the range of 2 kg in order to generate less heat, in accordance with those applied in this study.

The differences according to depth are probably influenced by bone density. Therefore with higher corticalization, higher force application can be expected (Yacker & Klein 1996). However, the ceramic drill at both depths, but especially in denser bone, needed less force applied during implant site preparations, indicating a better cutting efficiency, consistence with the SEM results.

The EDX results were essentially in agreement with the manufactures specification and the few published articles (Ercoli et al. 2004; Bayerlein et al. 2006).

SEM analysis, with various drill sections and various amplifications, detected slight signs of wear in both drills after 50 uses. These were more visible in the stainless steel drill. Gaertner et al. (2005) showed that after 10 uses of each ceramic and stainless steel drills, in an *in vivo* and *in vitro* study, the detected signs of wear were not significantly different. Also, Bayerlein et al. (2006), after performing 10 osteotomies in pig jaws, with 10 round Camlog® mixed ceramic burs did not detect signs of wear or fractures, concluding that burs with this composition might have promising applications in implantology. However, Scarano et al. (2007) only detected slight wear of 2 mm twisted high performance mixed ceramic drills (Dental Tech®, Misinto ,Milano) following 180 perforations and significative deformation and fractures following 210 perforations.

This study offers a new insight into ceramic drill mechanical characteristics during implant bone preparation and the effect of these in bone temperature variations. Although, we must recognize some limitations when critical assessing the results of this study. Firstly, temperature assessment was only evaluated with the use of one thermocouple positioned at a depth of 8 mm. Nonetheless, Ercoli et al. (2004) positioned two thermocouples at two different depths (5 and 15 mm), obtaining similar temperature results as the majority of reports, which only placed one thermocouple (Eriksson, et al. 1984a, 1984b; Iyer et al. 1997; Allan, et al. 2005; Chacon et al. 2006; Augustin et al. 2008). Secondly, the thermocouple was positioned 1.5 mm from the drilling site, as both cortical and cancellous bone were used, and this distance was considered necessary in order to ensure that the drill would not engage the thermocouple and destroy it, during the drilling process. Most studies that positioned the thermocouple 0.5 mm from the osteotomy site only used cortical bone (Ercoli et al. 2004; Chacon et al. 2006). Jochum and Reichart (2000) reported that changing the position from 0.3 to 0.7 mm, essentially the same temperatures were obtained. However, Bachus et al. (2000) registered lower temperatures when the thermocouples were positioned further away from the site preparation (0.5, 1 and 2 mm). This could be one factor that lead to slightly mean temperature increase obtained in this study (0.9°C–8 mm; 2°C–10 mm), when compared with others, such as, Ercoli et al. (2004) that positioned the thermocouple 1 mm

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from the drilling site, obtaining a mean temperature increase of 1.4°C at 5 mm and 2.5°C at 15 mm. Another factor could be the use of 1500 r.p.m. during drilling, while in this study only 800 r.p.m. were used. But even considering that the distance of 1.5 mm from the drilling site may lead to lower temperature values up to 2°C, as suggested by Abouzgia and Symington (1996), the temperature increase obtained for all perforations, in this study, did not exceed the critical bone temperature rise considered necessary to induce thermonecrosis (Matthews & Hirsch 1972; Eriksson & Albrektsson 1983; Eriksson et al. 1984a, 1984b; Ercoli et al. 2004; Cardoni et al. 2006). Thirdly, no attempt was made to simulate disinfection and sterilization during the experiment (drills were only cleaned with water). In this respect, Harris and Kohles (2001), showed that, autoclaving may decrease the cutting efficiency over time. Jochum and Reichart (2000) concluded that despite the fact of leading to higher loss of drill sharpness, sterilization and disinfection, did not seem to significantly increase drill temperature due to reusage when only cleaned with distillated water.

Nevertheless, as this is a comparative study, by using the same methodology, the values may be compared between both drills. Therefore, the only real limitations of this study are the limited sample of drills tested and the difference between the two drill designs. The latter is a restriction imposed by the manufacture, as similar designs with only different material are not commercially available.

Conclusions

An *in vitro* experimental protocol and mechanical apparatus was developed, in order to simulate clinical drilling protocol for oral implant placement, in a controlled manner. This protocol aimed to evaluate temperature changes and drill wear, after 50 uses, with the use of stainless steel and oxide Zr-based drills. Within the limitations of this study it is possible to conclude that:

1. Depth was the predominant factor influencing bone temperature increase, suggesting that with higher drilling depths, higher temperatures may be expected.
2. Drill material and design appear to influence bone temperature increase, as lower temperatures were obtained during implant site preparations with the ceramic drill.
3. Temperature increase is correlated with higher drill usage, as well as, the load applied during drilling.
4. No excessive signs of wear, deformation or fracture, with either drill were detected; even so the ceramic drill presented lower loss of sharpness.

However, as both drills after 50 implant site preparations did not produce the necessary bone temperature increase described to induce thermonecrosis, the clinical outcome most probably will be similar when using either drill with a correct drilling protocol. Nevertheless, further studies are necessary to fully comprehend the apparent benefits of mixed ceramic drills in implant site preparations.

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