Heat generation in one-piece implants during abutment preparation with high-speed cutting instruments

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Abstract

Background: The effects of heat generated during intraoral abutment preparations, how it is transferred in one-piece implant designs, and what effects it may have on crestal bone loss are not yet entirely understood. ***Materials and methods:*** Standard one-piece implants (n = 18) with conventional abutment sections and *Zimmer*® One-Piece Implants (n = 18) with contoured abutment sections were selected for this study. Samples were suspended in a plastic holder and heat transference into the endosseous threaded region was recorded during abutment preparation with carbide or diamond burs, and with air spray or water coolant. ***Results:*** Abutment preparations significantly elevated surface temperatures. Concentrations were highest in the crestal bone region and progressively diminished in the apical direction. Heat intensity and duration were proportionate to abutment length and preparation time. ***Conclusions:*** *Zimmer* One-Piece Implants significantly reduced abutment preparation time and heat concentrations in the crestal bone region. Use of water irrigation was crucial for preventing thermal damage to the bone for both implant designs. A link between excessive temperature concentrations and crestal bone loss is suspected, but could not be determined by this study.

Introduction

During dental implant placement and restoration, temperature rise in the alveolar bone is a clinical concern because of its potential to cause bone damage and compromise osseointegration.[1-3] Research has shown that the threshold level for heat-induced cortical bone necrosis is 47°C (116.6° F) for 1 minute,[1] and that excessive frictional heat generated during osteotomy preparation can impair the turnover activity of bone tissue by causing hyperemia, necrosis, fibrosis, osteocytic degeneration and increased osteoclastic activity.[4-7] After drilling, a zone of devitalized bone forms around the outer walls of the osteotomy, and the extent of the necrotic zone will vary exponentially based on the magnitude of the drilling temperature.[8-9] Rabbit tibia heated to 50° C (122.1° F) for 1 minute and 47° C (116.6° F) for 5 minutes has been shown to exhibit 30% to 40% bone resorption in the observation area after 40 days.[1] When this same tibia bone was heated to 47° C (116.6° F) for 1 minute, cellular damage and bone injury were observed.[1]

Barclay et al.[10] assessed the range of temperatures encountered in various intraoral sites during the intake of hot or cold liquids. Hot fluids were capable of raising the intraoral temperature of the anterior teeth to approximately 70° C (158° F), but heat transference to the supporting hard and soft tissues was not evaluated. Since metals, such as titanium and titanium alloy, are excellent thermal conductors, the impact of secondary heat generation on peri-implant bone is a clinical concern. Ormianer et al.[11] recorded temperature changes in implants of patients who drank hot beverages, and found maximum temperatures of 47.3°C (117.1° F) at the abutment, 45.6°C (114.1° F) at the implant's internal space, and 44.6°C (112.3° F) at the implant-abutment interface. A linear correlation was found between the temperatures measured (i) at the implant abutment and in the implant's internal space, and (ii) at the abutment and at the abutment-implant interface.[11] Other studies investigated the transference of heat generated by autopolymerizing acrylics[12] and dental plasters,[13] and found that they posed a risk of potentially damaging heat transfer to the bone-implant interface. Outcomes have been mixed, however, regarding heat transfer during laser-decontamination of implant surfaces.[14-17]

Previous studies on heat generation during abutment preparation using a two-piece implant system (implant + abutment) showed that temperature increase in the implant body at the cervix and apex varied according to grinding conditions, the type of bur and the type of coolant used.[18-22] It should be noted, however, that the implant-abutment interface of the two-piece implant system has different boundary conditions than one-piece implant designs. The boundary condition posed by an implant-abutment connection may alter the heat transfer characteristics of the implant system as compared to the solid transition from the abutment to implant regions of a one-piece implant. It is currently unknown, however, how variations in abutment geometry may also affect the creation and transference of thermal energy in dental implants.

This paper reports on the findings of an *in vitro* study that was undertaken to evaluate heat generation and transference in one-piece implants with two different abutment geometries subjected to routine clinical abutment preparations.

Materials and methods

Study samples were one-piece implants designed with the same threaded endosseous section, 3.7 mm x 13 mm with a micro-textured (MTX™, Zimmer Dental Inc., Carlsbad, CA) surface, but with differing abutment sections. The standard one-piece implant featured a conventional abutment section that required substantial modifications to create an appropriate restorative profile and margin, and the *Zimmer* One-Piece Implant (Zimmer Dental Inc., Carlsbad, CA) that featured an established margin and restorative profile designed to minimize or eliminate the need for preparations.

Many commercially available one-piece implants require preparations similar to the control one-piece implant. It was hypothesized that such extensive preparations would cause a significant temperature rise in the implant body, but that such an increase would not pose a thermal hazard to the peri-implant bone. A second hypothesis was that the minimal preparations required by the design of the *Zimmer* One-Piece Implant would limit both the extent and duration of temperature rise in the implant body, and that such a limited increase would not pose a thermal hazard to the peri-implant bone.

A total of 36 implants (*Zimmer* One-Piece Implants = 18, standard one-piece implants = 18) were divided into 8 groups subjected to different preparation methods **[Table 1]**. Sample sizes in this study were based on those of comparable predicate studies, and represented the minimum requirements to have statistical power.[19-20] Each study sample was screwed partially through a threaded hole of an acetyl homopolymer resin (Delrin, DuPont, Wilmington, DE) holding device with a depression in the top so that irrigation water drained away from the test sample with the assistance of a drainage tube **[Fig. 1]**. The threaded hole in the holding device was checked prior to each test. If the thread was found to be damaged, a new hole was used to ensure secure fixation of the implant.

After placement in the holding device, the threaded area of the implant remained exposed **[Fig. 2]** for measuring temperature changes using an infrared camera and software (ThermoVision A40 Camera and ThermaCAM Researcher Software, FLIR Systems, Inc., Boston, MA). Care was taken to ensure that the infrared camera had an unobstructed view of the implant and holding device. For each test sample, temperature data of the entire threaded viewing area were recorded (320 x 240 resolution) as a continuous image file at 7.5 frames per second for entire testing period using the

Fig 1. Zimmer *One-Piece Implant (arrow) screwed into the study holding device.*

Fig 2. *Threaded area of the implant is positioned for clear viewing by the infrared camera.*

Table 1. Study implants

Sample			**Method of preparation**	
Type	Group no.	Qty.	Bur	Coolant
***Zimmer* One-Piece Implants**	1	6	Carbide	Air
	2	6	Carbide	Water
	3	3	Diamond	Air
	4	3	Diamond	Water
Standard one-Piece Implants	5	6	Carbide	Air
	6	6	Carbide	Water
	7	3	Diamond	Air
	8	3	Diamond	Water

infrared camera. Time vs. temperature data were extracted 1 mm below the holding device plate (SP01), the middle of threaded region (SP02), and 1 mm above the apex (SP03). Data from the infrared camera image of each study sample were collected and stored at a sampling rate of 0.66 Hz, and then subsequently analyzed.

For the test, implants were modified with carbide (Carbide Bur H283.31.010, Brasseler USA, Savannah, GA) or diamond (Diamond Bur 6878.31.014, Brasseler USA) burs in a high-speed handpiece (GENTLEsilence LUX 6500B, KaVo Dental Corp., Lake Zurich, IL). During all modifications, the study samples were cooled with either air spray or water irrigation kept at 19.4° C ± 0.6° C (66.9° F ± 4.3° F). Prior to the study, research engineers were trained by a Certified Dental Technician (CDT) in appropriate laboratory grinding procedures so that abutment preparations made during the test were performed according to standard clinical techniques. Abutment sections were reduced 1.5-2.0 mm and one side was modified to approximate a 30° angle **[Fig. 3]**.

Fig 3. *Prepared abutment section of the* Zimmer *One-Piece Implant showing reduced height (arrow) and increased angulation.*

Carbide burs were inspected after each use and changed when visible wear was noted, or automatically replaced after preparing a single group of 6 specimens. Diamond burs were replaced after preparing 1 specimen. After grinding, samples prepared with water irrigation were allowed to cool for 6 minutes, while those prepared with air spray were allowed to cool for 10 minutes. Thermal data readings were also recorded during cooling times.

Results

Infrared imaging of all one-piece implant surfaces during abutment section preparations showed that the highest heat elevations were concentrated in the endosseous crestal bone region (SP01) **[Fig. 4]**, regardless of abutment section design or whether air spray or water irrigation was used. While thermal damage to bone tissue has been well documented[1-9] in the scientific literature, the effects of small temperature concentrations on crestal bone maintenance and stability are still unknown.

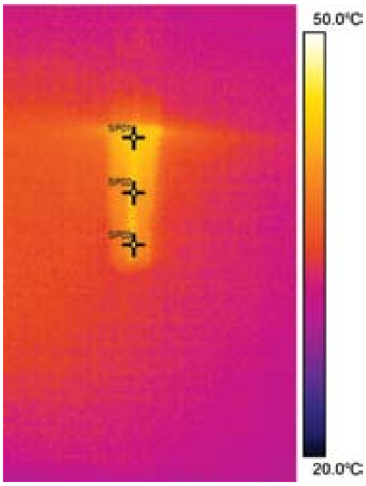

Fig 4. *Infrared image of implant and surrounding area, with locations of temperature measurement at the mid-point of grinding. The brighter colors represent higher temperatures, which progressively decreased in the apical direction from SP01 to SP02 and SP03, respectively.*

Average temperature changes in the crestal bone region (SP01) **[Table 2]** showed that grinding time, bur type and the presence or absence of irrigation coolant significantly affected implant surface temperature. *Zimmer* One-Piece Implants with contoured abutment sections required significantly less grinding time than the standard one-piece implants. Quadratic fitting $(y = ax^2 + bx + c)$ for both implant designs during the first 90 seconds of grinding with air spray was conducted to investigate the rate of temperature changes (dT/dt) **[Table 3]**. Results demonstrated that *Zimmer* One-Piece Implants had significantly lower rates of temperature increase compared to standard one-piece implants, regardless of the type of bur used **[Table 3]**.

Significant temperature increases were observed when abutment sections were prepared without water irrigation, regardless of implant design or bur type, and the highest temperatures were still concentrated in the crestal bone regions (SP01) **[Fig. 5]**. When water coolant was used, however, the implant surface temperature initially decreased after the start of grinding and then slightly increased at the end of the grinding period, but there was no significant temperature increase at any location on the implant surface during preparations, regardless of implant or bur type **[Fig. 6]**. Among *Zimmer* One-Piece Implants prepared with water irrigation, use of a diamond bur (group 4) resulted in a temperature increase because longer preparation time was needed, whereas those prepared with a carbide bur (group 2) showed no increase in surface temperature. Among standard one-piece implants prepared with irrigation coolant (groups 6 and 8), a temperature increase occurred at the end of the grinding period after an initial temperature drop, regardless of bur type, because of longer grinding times required for the larger abutment sections; however, the maximum temperature increase was not significantly higher than the initial temperature of the implant prior to grinding.

Table 2. Summary of average temperature changes in the crestal bone region (SP01). *, °, ^ and § represent significant difference ($p<0.05$).

Sample			Average temperature (°C)		
Type	Group no.	Variables	Initial	Maximum rise	Difference
Zimmer One-Piece Implants	1	Carbide bur, no irrigation	25.61	41.91	16.30^§
	2	Carbide bur, water irrigation	23.69	23.93	0.24
	3	Diamond bur, no irrigation	26.12	39.50	13.39*°
	4	Diamond bur, water irrigation	23.99	24.21	0.22
Standard one-piece implants	5	Carbide bur, no irrigation	25.43	45.43	20.00*^
	6	Carbide bur, water irrigation	23.72	23.91	0.18
	7	Diamond bur, no irrigation	25.39	46.70	21.31°§
	8	Diamond bur, water irrigation	23.04	23.32	0.28

Table 3. Derivative of quadratic fitting and temperature increase rate during the first 30 seconds of grinding for groups 1, 3, 5, and 7

Derivative of quadratic fitting ($dy/dt = dT/dt = a'x + b'$)*	*Zimmer* One-Piece Implants				Standard one-piece implants			
	Group 1 (carbide bur, no irrigation)		Group 3 (diamond bur, no irrigation)		Group 5 (carbide bur, no irrigation)		Group 7 (diamond bur, no irrigation)	
	a'	*b'*	*a'*	*b'*	*a'*	*b'*	*a'*	*b'*
	0.0023	0.0355	-0.0008	0.1218	-0.0036	0.3025	-0.0057	0.3788
	Temperature increase rate (dT/dt)* [°C/second]							
Time [s]	*dT/dt*		*dT/dt*		*dT/dt*		*dT/dt*	
1	0.0378		0.1214		0.2989		0.3760	
5	0.0470		0.1198		0.2845		0.3648	
10	0.0585		0.1178		0.2665		0.3508	
15	0.0700		0.1158		0.2485		0.3368	
20	0.0815		0.1138		0.2305		0.3228	
25	0.0930		0.1118		0.2125		0.3088	
30	0.1045		0.1098		0.1945		0.2948	

*T = temperature; t = time

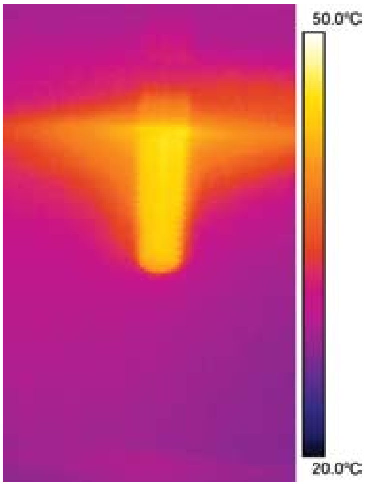

Fig 5. *Infrared image shows highest temperature increase at the crestal bone region after grinding with only air coolant (specimen 4, group 1).*

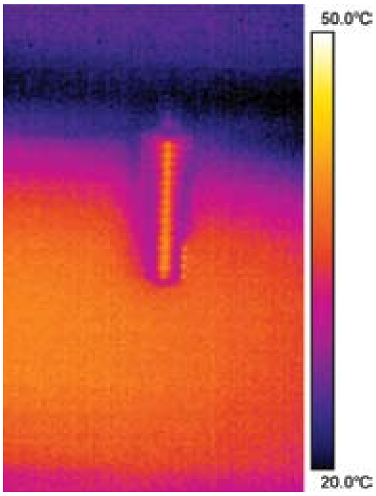

Fig 6. *Infrared image at the end of grinding period with water coolant shows no temperature increase through the implant surface (specimen 1, group 2).*

Data comparisons showed that temperature increases were significantly lower for *Zimmer* One-Piece Implants compared to the standard one-piece implants, regardless of the bur type, when air spray was used ($p < 0.05$). When water coolant was used, no significant temperature differences were found before and after grinding, regardless of the implant design or bur type; however, a slight temperature increase during the grinding period was observed when a diamond bur or standard one-piece implant was used. For the *Zimmer* One-Piece Implant, use of different burs did not cause a significant difference in temperature increase regardless of whether air spray or water irrigation was used, although grinding with a diamond bur took longer to achieve same abutment geometry as it did with a carbide bur.

Quadratic fitting results demonstrated that standard one-piece implants exhibited not only higher temperature rise during the grinding procedure, but also higher temperature increase rate (dT/dt) at the beginning of the grinding process.

Data suggest that standard one-piece implants will reach higher temperatures in a shorter period of time and subject the crestal bone to higher temperatures for a longer period of time than *Zimmer* One-Piece Implants.

Discussion

In this study, the amount of heat generated within the bodies of one-piece implants during routine clinical abutment preparations was investigated using infrared camera. Results showed that abutment preparation with high-speed carbide and diamond burs significantly increased implant surface temperatures when air spray was used as a coolant. The use of water irrigation was critical to limit this increase.

A worst-case temperature increase of 21.31° C (70.1° F) was observed when the standard one-piece implant was prepared with a diamond bur and air spray was used as a coolant. The analogous conditions when preparing the *Zimmer* One-Piece Implant yielded a temperature increase of 13.39°C (56.1°F). These results satisfied the study hypothesis that the limited grinding required by the contoured shape of the *Zimmer* One-Piece Implant's abutment section resulted in lower heat generation in the bone. The lower temperature increase rate of *Zimmer* One-Piece Implants at the early period of grinding was also a significant finding of this study, and may be attributable to the low-contact pressure required to remove only a small amount of material from the contoured abutment section. This may also limit the rate of temperature increase, and thus minimize the time that the bone is exposed to high and potentially harmful temperature concentrations.

Conclusions

Preparing abutment sections of one-piece implants can significantly elevate surface temperatures throughout the endosseous region of the implant. Highest heat concentrations occur in the crestal bone region and progressively diminish in the apical direction. The intensity and duration of the generated heat are proportionate to the length of the abutment section and amount of time required to prepare it. A link between these temperature concentrations and crestal bone loss is suspected, but could not be determined by this study. *Zimmer* One-Piece Implants were found to significantly reduce abutment preparation time and heat concentrations in the crestal bone region. Use of water irrigation during preparation of one-piece implants is crucial for preventing thermal damage to the bone.

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