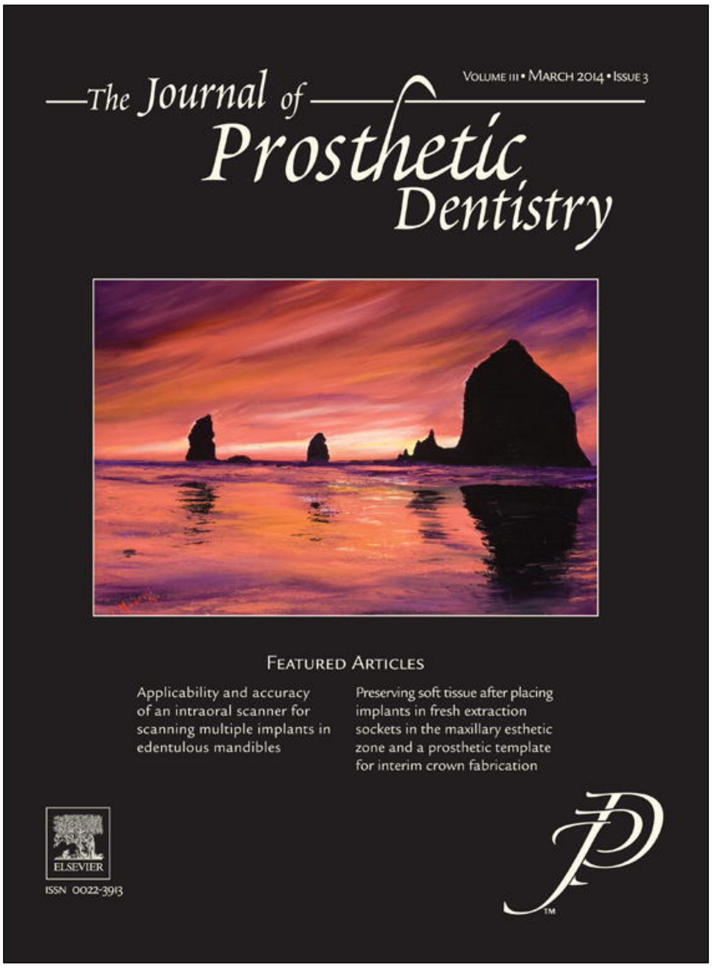
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Evaluation of heat conduction in dental implants after exposure to hot beverages

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Statement of problem. It is unknown if the consumption of hot beverages after implant placement poses a danger of overheating at the bone-implant interface.

Purpose. The purpose of this study was to investigate the effect of simulated consumption of hot beverages on the heat transfer to different dental implant types, implant sizes, and the presence of an interim restoration.

Material and methods. A model that consisted of 2 plastic containers was constructed to simulate the oral cavity and endosseous region of the jaw. One-piece and 2-piece implants with abutments were placed into a block of bovine mandibular bone without any healing tissue, surrounded by water maintained at 37°C in the lower compartment. The abutments, which extended into the upper container, were covered with water heated to 60°C to simulate consumption of a hot substance and then were cooled down spontaneously to 37°C during 100 to 600 seconds. Five thermocouple electrodes with an accuracy of ±0.1°C were attached to each test specimen and to a computer with data recording and analysis software to record temperature changes. Repeated measures ANOVA (α=.05)was performed to determine the effect of each major factor.

Results. Heat conduction from the abutment exposed to hot liquid was significantly higher in the cervical as opposed to the apical areas of the implants. Implant type (1 piece), diameter (wider), and the absence of an interim coping had a significant effect on the maximum temperature measured and on the temperature change rate.

Conclusions. Abutment exposure to hot liquids resulted in heat conduction to the cervical region of the implant, which could be biologically harmful in healing tissues. Heat conduction was mitigated by implant design and diameter, and by the presence of an interim prosthesis. Results may differ in clinical models. (J Prosthet Dent 2014;111:228-233)

Clinical Implications

Although the present laboratory model with bovine bone cannot be directly equated with heat conduction with implants placed in vital human bone, analysis of the results suggests that patients should be cautioned to avoid hot foods and liquids until soft-tissue healing can provide some insulation to the implant against excessive heat conduction.

Early studies reported that crestal bone loss during the first year of function (prosthetic loading) often involved the first thread of the implant; however, the understanding of the threshold between acceptable and pathologic marginal bone loss has changed over time.[1-3] Subsequent studies have precisely quantified that vertical bone loss should be less than 0.2 mm annually after the implant's first year of service but discounted all periimplant bone loss that occurred from implant placement through the first year of functional loading.[4]

More recently, research has moved away from attempts to quantify an acceptable range of periimplant bone loss to a search for new methods of eradicating bone loss altogether. Improved surgical[5-7] and prosthodontic[8,9] techniques have generally helped to reduce marginal bone

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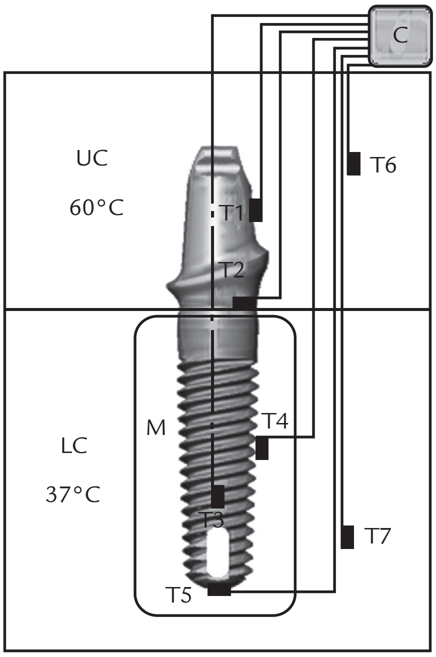
loss. Surgical trauma[7,10-12] and occlusal overloading[7,12-17] continue to be the most clinically documented causes of marginal bone loss and implant failure. In addition, excessive heat at the bone-implant interface may cause irreversible bone damage and compromise osseointegration. Heating the bone to 47°C for 1 minute or 40°C for 7 minutes during implant-site preparation can adversely affect implant survival.[1] Metals such as titanium or titanium alloy are excellent thermal conductors.[18-23] Therefore, the influence of heat generated through implant components to the periimplant tissues has been investigated.[18-23] Thermographic studies of abutment preparation of 2-piece implant-abutment assemblies have demonstrated that heat is transferred through the abutment into the implant body and that the highest temperatures were concentrated in the crestal bone region.[18-20] The temperature generated varied according to rotary instrument type, duration of the grinding procedure, and the presence or absence of external coolant (up to 4.7°C in 30 seconds).[19] Other studies also have demonstrated heat transfer through implant components from the setting of autopolymerizing acrylic resins applied to the abutment surface (4°C to 5°C above baseline in 2 minutes),[21] the intake of hot beverages (76.3°C in 30-60 seconds),[22] and the setting of impression plaster (53.6°C in 30-60 seconds).[23] Cortical necrosis and a delay of healing have been observed from overheating bone.[24,25]

The objective of this study was to determine whether there was a significant difference in heat transfer at different locations on the implant between different implant types (1-piece implant and 2-piece implants), implant sizes (3.7 and 4.7 mm), and with or without an interim restoration. The null hypothesis was that there would be no statistically significant differences in heat transfer to the endosseous sections of implants different in type, size, and restoration.

MATERIAL AND METHODS

A 2-compartment model for heat conduction analysis was fabricated (Fig. 1). Two-piece (Tapered Screw-Vent; Zimmer Dental Inc) and 1-piece (Zimmer One-Piece; Zimmer Dental Inc) implants, precontoured abutments (Hex-Lock Contour Abutment; Zimmer Dental Inc) and interim copings (Temporary Caps; Zimmer Dental Inc) were used in this study (Table I). Upper and lower compartments were separated by a plastic layer sealed with a rubber dam (Latex-Free Dental Rubber Dam; Aseptico). The upper compartment simulated the oral cavity, whereas the lower compartment simulated the body



1 Locations of thermocouple attachment: abutment (T1); abutment-implant interface (2-piece implants) or transition area (1-piece implants) (T2); apical vent (T3); mid-implant-bone interface (T4); and apical implant-bone interface (T5). Data were computer analyzed (C).

TABLE I. Test design

Test Group	Implant Category	Implant Size (mm)	Precontoured Abutment Yes/No	Precontoured Abutment Size (mm)	Interim Coping Yes/No	Interim Coping Size (mm)	Quantity (each item)
1	2P	3.7×10	Yes	3.5×4.5	No	–	24
2	2P	3.7×10	Yes	3.5×4.5	Yes	4.5	24
3	2P	4.7×10	Yes	4.5×5.5	No	–	24
4	2P	4.7×10	Yes	4.5×5.5	Yes	5.5	24
5	1P	3.7×10	–	–	No	–	24
6	1P	3.7×10	–	–	Yes	4.5	24
7	1P	4.7×10	–	–	No	–	24
8	1P	4.7×10	–	–	Yes	5.5	24

2P, 2-piece implant plus abutment assembly; 1P, 1-piece implant.
Note implant sizes and interim coping presence on some of implants.

tissues. Both compartments were used as water baths, and the sealed plastic sheet isolated the 2 baths from each other.

Each implant was placed into a block of bovine mandibular bone that measured 1.5×4×5 cm and was surrounded by water maintained at 37°C in the lower compartment of the test model. The water temperature was maintained with a thermoelectric generator (Dental Iceberg; Elmeko). A titanium-alloy abutment was connected to the coronal aspect of the 2-piece implant according to the manufacturer's directions, whereas the 1-piece implants had an integrated abutment section. Both implant-bone assemblies were placed into the upper chamber of the test model. Water with a temperature of 60°C was poured into the upper chamber to simulate consumption of a hot substance and then was cooled down spontaneously to 37°C over 100 to 600 seconds, according to locations along the length of the implant. Thermocouple electrodes (ZA9021FST T type NiCr Thermocouple Connector; Ahlborn Mess- und Regelungstechnik GmbH) of 0.2-mm diameter with an accuracy of ±0.1°C were used to record temperature changes. The thermocouple wires were insulated with silicone so that only the temperature at the exposed tip was measured.

All thermocouples were linked (ZA1919DKU USB Cable; Alhborn Mess- und Regelungstechnik GmbH) to a computer (Almemo; Alhborn Mess- und Regelungstechnik GmbH) with data recording (MA56902TG Data Logger; Alhborn Mess- und Regelungstechnik GmbH) and analysis software (SW5500WCO Control Software and OA5690S 512 KB Memory Option; Alhborn Mess- und Regelungstechnik GmbH). Five thermocouples were attached to each test specimen (Fig. 1). One additional thermocouple (T6) was left immersed in the upper compartment of the test model to measure the changes in the water temperature, and a final thermocouple (T7) was used to control the temperature of the lower compartment. Temperature changes were recorded by each thermocouple during the duration of the test at a rate of 1 specimen at 3-second intervals.

The interim restoration was fabricated from acrylic resin material (Pattern Resin LS; GC Corp) and an interim test restoration (Zimmer Dental Inc). Interim restorations were fabricated as solid cylinders that varied in height and diameter according to implant diameter and tooth location: cylinders 8.5×11 mm were fabricated for implants 3.7 mm in diameter for anterior tooth locations, and cylinders 11×10 mm were fabricated for implants 4.7 mm in diameter to simulate posterior teeth.

The interim coping was cemented to the test specimen with interim dental cement (TempBond NE; Kerr Corp). A small hole was placed in the interim coping to allow thermocouple (T1) access to the abutment surface beneath the crown. The hole was sealed with acrylic resin, interim cement, or other waterproof material. Because the test was nondestructive, the same implant-bone assemblies were tested first without and then with the interim coping in place (Table I).

Temperatures were measured at the abutment and in different locations on the implant during the entire testing period, from t=0 to t=end. The maximum temperatures between the abutment and the implant were analyzed by means of coefficient of determination (R^2) data (multiple regression analysis). The maximum temperature and the maximum temperature increase rate between the different locations on the implant were also analyzed with paired *t* tests with 2-tailed distribution. The effects of implant type (1-piece vs 2-piece configuration), implant diameter (3.7 mm vs 4.7 mm), and the presence or absence of the interim restoration on the temperature profile along the implants were analyzed with 2-way (type, size) and 1-way repeated measure (restoration) ANOVA (α=.05). Repeated measures ANOVA was performed to determine the effect of each major factor and its interactions. Repeated measures were used because the same implant was used with and without the interim restoration.

RESULTS

The temperature measurement from the abutment-implant interface (T2) was excluded from the analysis because its temperature profile was almost identical to that from the abutment (T1). Therefore, only temperature measurements from T3, T4, and T5 were analyzed. The R^2 of correlation among the measured temperatures at the abutment versus those at the implant apex, vent, and mid implant were calculated (Table II). The R^2 of correlation between the measured temperatures of the abutment versus apex, abutment versus vent, and abutment versus mid implant showed a higher correlation at the mid implant, followed by the vent and then the apex. Also, all groups tested showed that the R^2 value at the mid implant was significantly higher than that at the vent and apex. Most groups also showed differences between the vent and apex, except groups of 2-piece implants, diameter 3.7 mm/4.7 mm with interim coping.

Maximum temperatures at the implant apex, vent, and mid-implant regions were measured, and the results from a paired *t* test with 2-tailed distribution are shown in Table II. The results showed that the maximum temperature at the mid implant for all tested groups was significantly higher than that at the vent or the apex. The maximum temperature at the vent for all tested groups also showed a significant difference from that at the apex. Most tested groups showed that the maximum temperature was decreased with the use of interim coping, except the 1-piece, 4.7-mm-diameter group (Table II). The maximum rates of temperature increase (*dT/dt*) at the apex, vent, and mid implant are shown in Table II. The rate of change at the mid implant was significantly higher than that at the vent and the apex, and the rate of change was decreased for all groups with use of the interim coping.

Table II. Temperature and maximum temperature changes measured on different implant locations: Comparisons of temperature data

Test Group[a]	Apex (T5)	Vent (T3)	Mid (T4)
Coefficient of determination (R^2) of correlation vs T1			
1	0.24 ±0.17	0.12 ±0.17	0.65 ±0.14
2	0.10 ±0.11	0.33 ±0.26	0.79 ±0.17
3	0.08 ±0.15	0.43 ±0.18	0.76 ±0.18
4	0.25 ±0.17	0.75 ±0.16	0.95 ±0.09
5	0.21 ±0.17	0.11 ±0.16	0.39 ±0.20
6	0.13 ±0.12	0.14 ±0.19	0.53 ±0.22
7	0.16 ±0.13	0.45 ±0.20	0.68 ±0.15
8	0.13 ±0.12	0.14 ±0.19	0.53 ±0.22
Maximum temperatures from each measuring location			
1	38.33 ±1.14	39.48 ±0.64[b]	42.36 ±1.32[c]
2	37.12 ±0.58	39.37 ±0.77[b]	42.14 ±1.80[c]
3	40.92 ±1.07	44.27 ±1.38[b]	47.63 ±2.08[c]
4	41.95 ±0.90	44.84 ±1.38[b]	47.69 ±1.95[c]
5	38.43 ±1.06	40.08 ±0.76[b]	42.11 ±1.00[c]
6	37.43 ±0.59	38.40 ±0.79[b]	40.55 ±0.74[c]
7	40.47 ±0.69	42.31 ±0.90[b]	44.27 ±1.15[c]
8	37.43 ±0.59	38.40 ±0.79[b]	40.55 ±0.74[c]
Maximum temperature increase rate (dT/dt) at each measuring location			
1	0.32 ±0.36	0.41 ±0.26	0.73 ±0.39[d]
2	0.31 ±0.12	0.18 ±0.06[e]	0.54 ±0.15[d]
3	0.40 ±0.13	0.75 ±0.16[e]	1.14 ±0.33[d]
4	0.27 ±0.04	0.60 ±0.13[e]	0.94 ±0.22[d]
5	0.22 ±0.36	0.28 ±0.20	0.71 ±0.34[d]
6	0.12 ±0.10	0.15 ±0.06	0.40 ±0.37[d]
7	0.18 ±0.10	0.26 ±0.05[e]	0.49 ±0.12[d]
8	0.12 ±0.10	0.15 ±0.06	0.40 ±0.37[d]

[a]See Table I for test group descriptions.
[b]Significant difference of vent from apex (paired *t* test with 2-tailed, $P<0.05$).
[c]Significant difference of mid from apex and vent data (paired *t* test with 2-tailed, $P<0.05$).
[d]Significant difference of vent from apex (paired *t* test with 2-tailed, $P<0.05$).
[e]Significant difference of mid from apex and vent data (paired *t* test with 2-tailed, $P<0.05$).

A summary of results from data collected at the apex (T5), vent (T3), and mid implant (T4) location are shown in Table III. Two-way ANOVA results demonstrated that the implant diameter and interim restoration significantly interacted for the maximum temperature but that the rate of increase was not significant at any measurement location. Implant type (1 or 2 piece) and implant diameter affected the rate of temperature increase at the vent. The interactions of implant type and implant diameter affected the rate of temperature increase at the midsection of the implant (T4). Repeated measures ANOVA showed that nearly all the variables had a significant effect on all measurements and measurement locations. The only exception was that diameter did not have a significant effect on the maximum rate of temperature change at the apex (T5).

DISCUSSION

The null hypothesis of this study was rejected because, based on the finding that larger-diameter 1-piece implants may have the disadvantage of greater heat conduction properties compared with smaller-diameter 2-piece implants. Results of the present study showed that the effects of heat conduction from the abutment due to hot liquid consumption were more significant in the cervical areas than in the apical areas of the implant, which suggests that longer implants may not be more susceptible to heat conduction and retention than shorter implants. Implant type (1 piece) and diameter (wider), and the absence of an interim coping had a significant effect on the maximum temperature measured and on the temperature change rate.

These findings were corroborated by previous studies that found that heat was transferred through the abutment into the implant body and that the highest temperatures concentrated in the crestal bone region.[20-22] During the experiment, temperatures recorded at T3, T4, and T5 ranged from 37.4°C to 47.7°C, but temperatures at T2 (abutment-implant interface) were almost identical to those recorded at T1 (abutment). Analysis of the data showed that the T2 temperatures reached as high as 60°C (equivalent to the temperature of the poured water) and maintained a temperature higher than 50°C for more than a minute. Another test group (1 piece, 4.7 mm) (Table II) also showed that temperatures at T4 (mid implant) were higher than 47°C, even with the use of an interim coping, although the duration of temperature was less than a minute. Because of their proximity to critical temperature and duration thresholds, these temperatures may be a potential hazard to bone healing and should be avoided with proper procedures.

TABLE III. ANOVA table (α=.05) of maximum temperature and maximum increase rate by implant regions

Location	Variable	Maximum Temperature	Rate
Apex (T5)		Interaction effect of 2 major factors	
	Type - diameter	Significant	Not significant
	Type - restoration	Significant	Not significant
	Diameter - restoration	Not significant	Not significant
		Effect of each major factor	
	Type	Significant (1 piece > 2 piece)	Significant (1 piece > 2 piece)
	Diameter	Significant (4.7 mm > 3.7 mm)	Not Significant
	Restoration	Significant (no > yes)	Significant (no > yes)
Mid (T4)		Interaction effect of 2 major factors	
	Type - diameter	Significant	Significant
	Type - restoration	Significant	Not significant
	Diameter - restoration	Significant	Not significant
		Effect of each major factor	
	Type	Significant (1 piece > 2 piece)	Significant (1 piece > 2 piece)
	Diameter	Significant (4.7 mm > 3.7 mm)	Significant (4.7 mm > 3.7 mm)
	Restoration	Significant (no > yes)	Significant (no > yes)
Vent (T3)		Interaction effect of 2 major factors	
	Type - diameter	Significant	Significant
	Type - restoration	Significant	Not significant
	Diameter - restoration	Significant	Not significant
		Effect of each major factor	
	Type	Significant (1 piece > 2 piece)	Significant (1 piece > 2 piece)
	Diameter	Significant (4.7 mm > 3.7 mm)	Significant (4.7 mm > 3.7 mm)
	Restoration	Significant (no > yes)	Significant (no > yes)

Analysis of the results also showed that heat increase and overall heat conduction in the implant system were affected by implant type and diameter, and by the presence of an interim restoration. Multiple regression results showed that the maximum temperatures at all measurement locations were most significantly affected by the implant diameter, followed by implant type, and then by the presence of an interim restoration. The maximum rate of temperature change results showed that the implant type had the most significant effect on all the measuring points. This can be explained by geometrical differences between the 1- and 2-piece implants: the former has a continuum unibody, whereas the latter implant has a discontinuous body, which resulted in faster heat conduction at early time points. Higher maximum temperatures also were seen on the larger-diameter implants, which may be due to the increase in mass.

This study was based on a concern that the intake of hot beverages would cause a rise in temperature along the implant that, in turn, might damage the surrounding tissues. Critical points not addressed in the present study are the maximum temperature increases and associated time intervals that would occur for these implants and materials in clinical conditions with vital human bone compared with the present findings based on bovine bone and laboratory conditions. Subjecting nonhealed tissues to such elevated temperatures could adversely traumatize the bone-implant interface, especially in the crestal bone region, and result in progressive vertical bone loss. Therefore, this study was conducted to determine whether there was a significant difference in heat transfer between 1- and 2-piece implants, 3.7- and 4.7-mm-diameter implants, and implants with and without an interim restoration that might potentially insulate the implant from exposure to hot substances. Thermocouples provided accurate measurements of heat changes at several measurement locations on the abutment, implant, and test model.

The use of interim restorations significantly reduced heat conduction in most situations. Analysis of the data reported here suggests that the use of proper components and procedures could minimize the potential of compromised osseointegration caused by the consumption of hot beverages. For example, use of nonmetal interim abutments, for example, as polyetheretherketone, might be indicated because of poorer heat conduction to the implant than titanium abutments, but the cervical region of the implant might still be adversely affected. A 2-stage surgical procedure could help to avoid the potentially deleterious effects on heat conduction into areas of healing tissues but that option is not available with 1-piece implants. To date, the impact of heat conduction has not been correlated to marginal bone loss, peri-implantitis, or implant survival.

Thermal damage to living tissue is related the magnitude of temperature elevation and the period of time that the tissue is subjected to damaging temperature.[1] Overheating the bone to 47°C for 1 minute or 40°C for 7 minutes during implant-site preparation has been reported to adversely affect implant survival.[1] Temperature rise must be minimized in any implant system after surgery to reduce the risk of compromised implant osseointegration. As a safeguard, patients should be instructed to avoid eating and drinking hot foods and beverages at least until soft-tissue healing occurs, which will help to insulate the implant from heat from the oral cavity.

CONCLUSION

In an in vitro model with bovine bone, exposure of abutments to hot liquids resulted in heat conduction to the cervical region of the implant, which could be harmful to healing tissues. The degree of heat conduction was mitigated by implant design, implant diameter, and the presence of an interim prosthesis.

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