An Investigation on Heat Transfer to the Implant-Bone Interface Due to Abutment Preparation With High-Speed Cutting Instruments

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Excessive heat generation at the implant-bone interface may cause irreversible bone damage and loss of osseointegration. The effect of heat generation in vitro at the implant surface caused by abutment reduction with medium- and extra-fine-grain diamond and tungsten burs in a high-speed dental turbine was examined. Titanium-alloy abutments connected to a titanium-alloy cylindrical implant embedded in an acrylic-resin mandible in a 37°C water bath were reduced horizontally and vertically. Temperature changes were recorded via embedded thermocouples at the cervix and apex of the implant surface. Analysis of variance for repeated measures was used to compare seven treatment groups. Thirty seconds of continuous cutting with standard turbine coolant caused a mean temperature increase of 1°C with a maximum of 2°C. Similar tungsten cutting caused a mean increase of 2°C with a maximum of 4.7°C, significantly higher than diamond reduction. Additional air-water spray for continuous tungsten cutting had no significant effect, while intermittent cutting for 15-second increments reduced the temperature increase by 75%. Thus, abutment reduction with medium-grit diamonds using intermittent pressure and normal turbine coolant is unlikely to cause an interface-temperature increase sufficient to cause irreversible bone damage and compromise osseointegration.
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Key words: cutting instrument, heat generation, implant abutment preparation, irrigation

Intraoral recontouring of fixed abutments, shortening of coping screws, or occlusal adjustment of metal or porcelain occlusal surfaces in implant-retained restorations all carry an inherent risk of heat transfer to the bone-implant interface. Potential damage to the bone and risk of compromising osseointegration at the interface have led to the belief that such preparation of metal or ceramo-metal surfaces directly connected to osseointegrated implants is contraindicated. The effect of overheating the bone at the interface may cause bone death and compromise the bone's ability to survive as a differentiated tissue.[1–3]

Studies in which a thermal chamber for intravital microscopy of heated bone was used have shown that bone tissues were sensitive to heating at 47°C.[1] Rabbit tibia heated to 50°C for 1 minute and 47°C for 5 minutes showed 30% to 40% bone resorption in the observation fields after 40 days, with bone tissue replaced by tissue dominated by fat cells. When the bone was heated to 47°C for 1 minute, fat-cell injury and inconsistent bone injury were observed. Endothelial cells of vascular tissue were more resistant to heating than bone and fat cells. Greater tissue injury was reported after heating to 53°C for 1 minute[2]; heating to temperatures of 60°C or more resulted in permanent vascular stasis and irreparable necrosis of the bone tissue.[3]

High-speed dental handpieces can generate high levels of thermal energy.[4] Temperature changes and thermal stress distribution in teeth resulting from

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high-speed tooth preparation are functions of rotation speed, type of cutting surface, force, and the nature of coolants.[4] Whereas air coolants alone cause an increase in pulpal temperature, high-speed tooth preparation with air-water coolants reduces intrapulpal temperatures.[5,6] This, however, may not be applicable to titanium, since its thermal conductivity and diffusivity is 300 times that of dentin.

Therefore, this in vitro study was designed to evaluate heat generation at the surface of a titanium-alloy implant caused by reduction of a titanium-alloy abutment with diamond and tungsten burs in a high-speed dental turbine.

Table 1 Number and Type of Cuttings in Experimental Model

		Horizontal		Vertical
Type of bur	Time (s)	Turbine	Turbine coolant + triple syringe (AWS)	Coolant
Diamond (medium)	30	5	–	5
Diamond (extra-fine)	30	5	–	5
Tungsten	30	5	5	
Tungsten	15	5	–	–

Materials and Methods

In Vitro Model Design. A noncoated cylindrical Integral titanium-alloy implant body 4 mm in diameter and 10 mm in length (Calcitek, Carlsbad, CA), was embedded in an acrylic-resin model of a human mandible (Fig 1). The acrylic-resin mandible was immersed in a water bath (Hanau, Buffalo, NY) with a thermostatic temperature-control mechanism maintaining the starting water temperature at 37°C. A titanium-alloy fixed abutment (Calcitek, Carlsbad, CA) with a 2-mm gingival cuff length was screwed into the implant body and isolated from the water level by a rubber dam tied off with dental floss at the cervix of the abutment and at distal peripheral abutments (Fig 2).

Temperature Recording System. Thermocouple electrodes were attached to a flattened peripheral surface of the embedded implant at the cervical and apical facial aspects of the implant body. The connecting electrode wires were insulated with silicone. An additional electrode was left immersed in the water bath to measure the water temperature, and one was suspended in the air to measure the ambient room temperature (Fig 2). Solid-state temperature sensors of 1 µA/Kelvin (Analogue Devices, Boston, MA) capable of measuring temperature changes of 0.1°C were connected to a monitoring system (Atlas 8600 Physiolos, Tel Aviv, Israel) and to a computer, with four bands recording real-time temperature (Fig 3). Data were recorded at a rate of one sample per 0.55 second.

Preparation of Abutments. A high-speed turbine handpiece (Cavo, Biberbach, Germany) with a rotation speed of 250,000 rpm was used at maximum free-running speed with air pressure of 20 psi and water flow of 48 cm^3 per min. The air-water coolant temperature was 20 ± 1°C. In one group of cuttings, an additional air-water spray (AWS) from a triple syringe was added with a water-flow rate of 100 cm^3 per min and a temperature of 20 ± 1°C.

Straight medium- and extra-fine-grit diamond burs (Strauss, Tel Aviv, Israel) and straight tungsten carbide burs (Zakaria Mailleffer, Ballaigues, Switzerland) were used to cut the titanium-alloy fixed abutment in horizontal and circumferential-rotational vertical directions (Fig 2).

All cuttings were performed by a single operator. Burs were replaced after five successive reductions. A high-velocity suction tip was held 2 cm from the abutment to remove the water-coolant spray that collected in the rubber dam. The rubber dam prevented the water-coolant spray from draining into the water bath and changing the temperature.

Horizontal cuts were made with the medium and extra-fine diamond and tungsten burs. A continuous force was applied for 30 seconds, which was designed to cut through the abutment and reduce 1 mm of height from the most superior aspect. For each successive cutting period of 30 seconds, the implant abutment was progressively reduced in 1 mm increments. Abutments were replaced after 5 mm of reduction in vertical height. In a pilot study, the difference in abutment height was shown to have no effect on temperature changes (Gross et al, unpublished data).

Intermittent horizontal reductions were made with tungsten burs and standard turbine coolant for 15 seconds, followed by a break of 30 seconds and a further 15 seconds with turbine coolant.

Vertical preparation was carried out with medium and extra-fine diamond burs designed to simulate abutment contouring, rather than horizontal reduction.

Thus, seven combinations of variables, comprising type of bur, direction of cutting, coolant, and cutting time, were used. Five successive cuttings were made for each set of variables for a total of 35 cuttings (Table 1).

Statistical Analysis. One-factor analysis of variance (ANOVA) for repeated measures and Fisher PLSD Post Hoc test were used to detect and locate differences between groups of abutment cuttings.

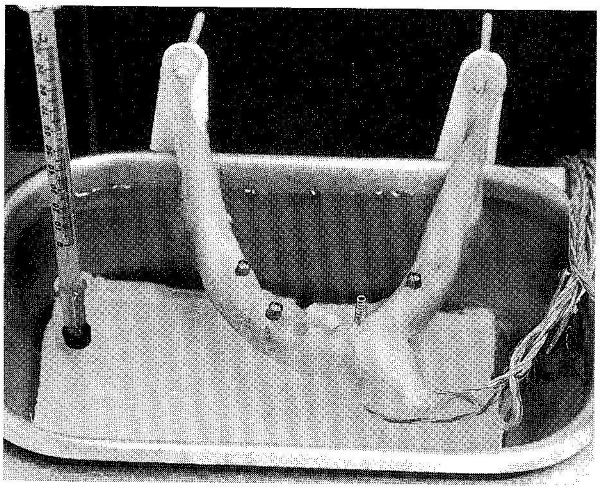

Fig 1 *(Above)* Acrylic-resin mandible with embedded implant and temperature sensors immersed in 37°C water bath.

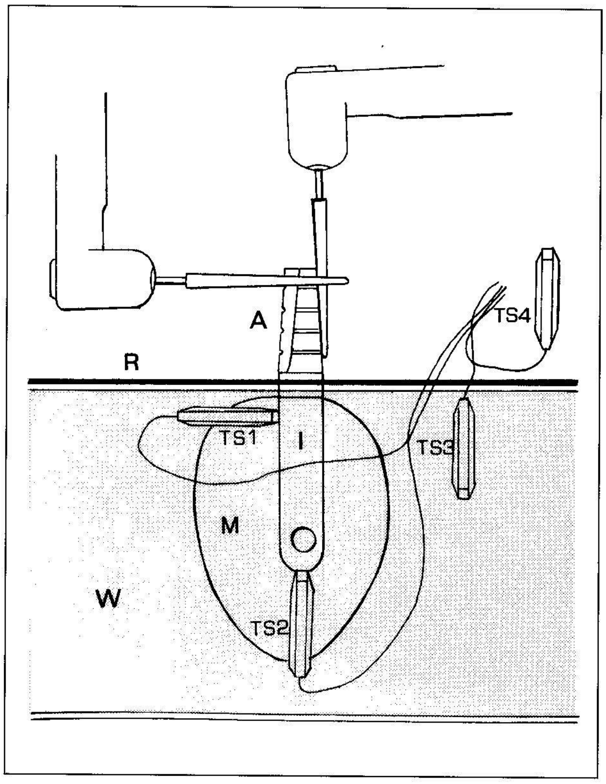

Fig 2 *(Right)* Schematic of horizontal and vertical cutting of titanium-alloy abutment (A) connected to a titanium-alloy implant (I) embedded in an acrylic-resin mandible (M) immersed in 37°C water (W). Rubber dam (R) isolates the water bath from the turbine coolant. Four temperature sensors are attached to the cervical (TS1) and apical (TS2) aspect of the implant, immersed in the water bath (TS3), and suspended in the air above the water bath (TS4).

Results

Mean and maximum temperature changes are shown in Figs 4 and 5. Statistical analyses are given in Tables 2 and 3.

Horizontal and Vertical Diamond Cutting. *Apical Changes.* All but one of the horizontal diamond reductions caused a mean increase in temperature of not more than 0.5°C. Vertical preparation with a medium-grit diamond bur caused a slightly greater increase of 0.9°C (SD 0.4) (Fig 4).

Cervical Changes. A decrease in temperature was seen with all diamond reductions.

Horizontal Tungsten Cutting. *Apical Changes.* Tungsten cutting with or without additional air-water spray caused a mean increase in temperature of 2.2°C (SD 0.9), which was significantly greater ($P < .05$) than all diamond cutting procedures (Fig 4).

Cervical Changes. Horizontal tungsten cutting with the normal coolant caused a mean cervical temperature increase of 2.0°C (SD 1.6) that was not significantly different from the apical change. Additional air-water coolant spray caused a decrease in temperature of 0.6°C (SD 0.8) similar to diamond cuttings ($P > .05$) and significantly different from other 30-second tungsten cuttings ($P < .05$) (Fig 4).

15-Second Intermittent Tungsten Cutting. The mean temperature increase was within the range of 0.05°C, significantly less than 30-second horizontal tungsten cutting ($P < .05$) and no different from diamond cutting ($P > .05$).

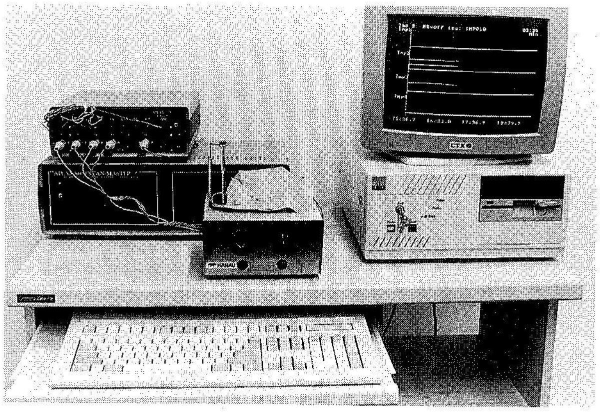

Fig 3 Water bath and temperature-monitoring system.

Maximum Temperature Changes. All diamond and intermittent tungsten cutting did not exceed 2°C from the baseline temperature of 37°C. Horizontal tungsten cutting of 30 seconds caused temperature increases from 2.7 to 4.7°C. Additional air-water spray reduced the temperature increase at the cervical region to 1.7°C (Fig 5).

Table 2 One-Factor ANOVA of Repeated Measures for Cervical Temperature Changes Resulting from Different Cutting Procedures (Treatments)

Source	*df*	Sum of squares	Mean square	F test	*P* value
Between					
cuttings	4	2.41	.6	.48	.7476
Within					
cuttings	30	37.43	1.25	–	–
treatments	6	25.09	4.18	8.14	.0001
residual	24	12.33	.51	–	–
Total	34	39.84	–	–	–

Table 3 One-Factor ANOVA of Repeated Measures for Apical Temperature Changes Resulting from Different Cutting Procedures (Treatments)

Source	*df*	Sum of squares	Mean square	F test	*P* value
Between					
cuttings	4	.92	.23	.21	.9326
Within					
cuttings	30	33.37	1.11	–	–
treatments	6	26.61	4.44	15.77	.0001
residual	24	6.75	.28	–	–
Total	34	34.29	–	–	–

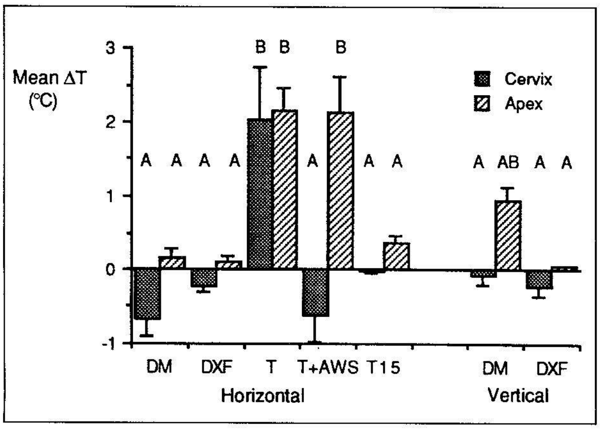

Fig 4 Mean temperature changes ΔT at the implant cervix and apex caused by horizontal and vertical abutment cutting. DM = medium-grit diamond. DXF = extra-fine diamond. T = tungsten carbide. AWS = additional air-water spray. A, B, and C: treatments with the same letter are not significantly different ($P > .05$). Vertical bar represents standard error of the mean.

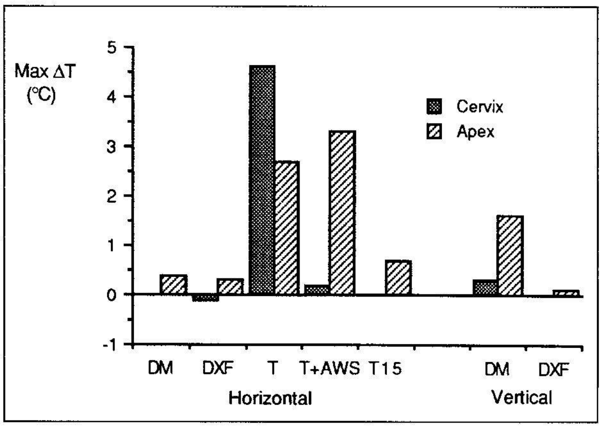

Fig 5 Maximum temperature changes ΔT at the implant cervix and apex caused by horizontal and vertical abutment cutting. DM = medium-grit diamond. DXF = extra-fine diamond. T = tungsten carbide. AWS = additional air-water spray. A, B, and C: treatments with the same letter are not significantly different ($P > .05$).

Discussion

The findings of this in vitro study indicate that cutting implant abutments for not more than 30 seconds with water coolants did not increase the implant surface temperature to more than 42°C from a starting temperature of 37°C. Cutting and shaping with medium or extra-fine diamond burs did not increase the temperature above 39°C. While tungsten burs increased the temperature more than the diamond burs, changes did not exceed 42°C. Temperature changes at the implant cervix were always less than the apex, probably the result of the proximity of the coolant spray. Although the thermal properties of titanium would suggest higher temperature rises for compared to dentin, it seems that these same thermal properties enhanced the effectiveness of the coolant.

Ericsson and Adell[7] reported a temperature increase in the bone adjacent to an implant-site preparation of 1.1°C, an increase not exceeded by the diamond reductions in this study. The importance of the coolant was indicated by a pilot study showing a 9°C increase from 30 seconds of tungsten cutting with no coolant, falling in the range of potential bone damage.[1] The continuous force applied for 30 seconds was used to simulate an exaggerated temperature increase. Intermittent cutting with turbine coolant caused an increase of not more than 0.5°C. Thus, intermittent cutting with coolant appears to be the optimum clinical technique required to induce minimal temperature changes if abutment or occlusal reduction is attempted intraorally.

No difference in heating as a consequence of a difference in abutment height of 5 mm was observed. Thus, reduction of abutments or occlusal surfaces with reduced interocclusal separation does not carry a greater risk of overheating supporting implants in this simulated in vitro model. High-speed abutment cutting with adequate cooling may not have deleterious thermal effects. However, it may effect the bone-implant interface through vibration. Usui et al[8] studied 20 to 60 minutes of mechanical vibration at 25 Hz on hydroxyapatite rods in rabbit tibia. No effects were observed regarding the rate and amount of new bone ingrowth. The effect of mechanical vibration on dental implants has yet to be studied.

Conclusions

Cutting and shaping titanium alloy abutments caused the following changes in the implant-body surface temperature:

1. Mean increase of 1°C with a maximum of less than 2°C for 30 seconds of continuous cutting with diamond burs and standard turbine coolant.
2. Mean increase of 2°C with a maximum of 4.7°C for 30 seconds of continuous cutting with tungsten burs and standard turbine coolant.
3. Additional air-water spray coolant had no significant effect.
4. Intermittent cutting with tungsten in 15-second increments reduced implant heating by 75%, compared with 30 seconds of continuous cutting.

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Résumé

Etude du transfert de chaleur à l'interface implant-os lors de la préparation des piliers à l'aide de fraises montées sur turbines

La production excessive de chaleur crée à l'interface implant-os peut causer un préjudice osseux irréversible ainsi qu'une perte d'ostéointégration. On étudia l'effet de la production de chaleur in vitro à la surface des implants causée par préparation des piliers à l'aide de fraises diamantées à granulométrie moyenne ou fine et de fraises au carbure de tungstène montées sur turbines. Des piliers en alliage de titane reliés à un implant cylindrique en alliage de titane enfoui dans une mandibule en résine acrylique placée dans un bain à 37°C furent réduits horizontalement et verticalement. Les changements de température furent enregistrés àtravers des thermocouples enfouis au col et à l'apex des surfaces de l'implant. L'ANOVA pour des mesures répetées fut utilisé afin de comparer sept groupes de traitement. Trente secondes de coupe continue à l'aide de refroidissement de turbine classique créa une augmentation moyenne de température de 1°C avec un maximum de 2°C. Une coupe similaire à l'aide de fraises en tungstène créa une augmentation moyenne de température de 2°C avec un maximum de 4,7°C., ce qui fut significativement plus élevé que la coupe à l'aide de fraises diamantées. Une irrigation supplémentaire pour une coupe continue à l'aide du tungstène n'eut pas d'effet significatif, tandis que des temps de coupe séparés et durant 15 secondes purent réduire l'augmentation de température de 75%. Ainsi, la réduction des piliers à l'aide de fraises diamantées à grains moyens et utilisant des intervalles de coupe et un refroidissement de turbine classsique ne causera vraisemblablement pas d'augmentation de température à l'interface susceptible de produire des lésions osseuses irréversibles et de compromettre l'ostéointégration.

Zusammenfassung

Untersuchung der Temperaturübertragung auf das Implantat-Knocheninterface durch hochtourige Abutmentpräparation

Übermäßige Hitzeentwicklung im Bereich des Implantat-Knocheninterface könnte zu irreversible Knochenschäden und zum Verlust der Osteointegration führen. Die Auswirkungen der Temperaturentwicklung an der Implantatoberfläche durch die hochtourige Abutmentpräparation mit Hilfe von mittel- und feinkörnigen Diamanten sowie Tungstenbohrern wurden in vitro untersucht. Aus Titanlegierung bestehende Abutments, welche mit aus dem gleichen Material bestehenden zylindrischen Implantaten verbunden wurden, wurden in einen Kunststoffunterkiefer eingebettet. Dieser Unterkiefer wurde in ein Wasserbad mit einer Temperatur von 37°C eingebracht. Darin wurden die Abutments vertical und horizontal beschliffen und Temperaturänderungen wurden durch eingebettete Thermoelemente im Hals- und Apexbereich der Implantatoberfläche registriert. Die 7 Behandlungsgruppen wurden mit Hilfe einer ANOVA für wiederholte Messungen verglichen. 30 Sekunden langes Präparieren mit Kuhlung erzeugte einen durchschnittlichen Temperaturanstieg von 1°C mit einem Maximum von 2°C. Ähnliches Beschleifen mit Tungstenbohrem ergab einen mittleren Anstieg von 2°C mit einem Maximum von 4,7°C, was signifikant höher lag als mit Diamanten. Zusätzliches Luft-Wasserspray fiir die ununterbrochene Präparation mit Tungstenbohrern erzielte keine signifikanten Unterschiede, jedoch reduzierte intermittierendes Beschleifen im 15 sec Intervall die Temperatur um 75 %. Somit ist es unter Verwendung der intermittierenden Abutmentpräparation mit mittelkörnigen Diamanten und normaler Turbinenkuhlung unwahrscheinlich, einen Temperaturanstieg im Interfacebereich zu verursachen, der zu irreversiblen Knochenschäden und eingeschränkter Osteointegration führt .

Resumen

Investigación sobre la transferencia de calor a la interfase hueso-implante debido a la preparación del pilar con instrumentos de corte a base de alta velocidad

La producción de calor excesivo en la interfase hueso-implante puede causar un daño irreversible al hueso y la pérdida de la oseointegración. Se examinó el efecto de la producción de calor in vitro en la superficie del implante, causada por la reducción del pilar con fresas de tungsteno y de diamante de grano mediano y fino con turbinas dentales utilizando alta velocidad. Se redujeron horizontal y verticalmente los pilares de aleación de titanio conectados a un implante cilíndrico de aleación de titanio incrustado en una mandíbula de resina acrílica en un baño de agua de 37°C. Se registraron los cambios en la temperatura por medio de termocuplas incrustadas en el cérvix y ápice de la superficie del implante. El análisis de varianza utilizando medidas repetidas fue utilizado para comparar siete grupos de tratamiento. Los cortes continuos por 30 segundos con un refrigerante de turbina estándar causaron la elevación media de la temperatura de 1°C con una máxima de 2°C. El corte similar realizado con tungsteno causó una elevación media de 2°C con una máxima de 4,7°C, lo cual fue significativamente mayor que en el caso de la reducción con diamante. Al adicionar agua atomizada cuando se utilizó el tungsteno para corte continuo, no se determinó un efecto significativo, mientras que el corte intermitente con incrementos de 15 segundos redujeron el aumento de la temperatura en un 75%. Por lo tanto, es improbable que la reducción del pilar por medio de diamantes de dureza mediana utilizando presión intermitente y un refrigerante de turbina normal, cause un aumento de la temperatura de la interfase suficiente para causar daño irreversible al hueso y el compromentimiento de la oseointegración.