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Review

Heat generation and drill wear during dental implant site preparation: systematic review

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Abstract

To identify factors that minimise damage during the drilling of sites for dental implants, we reviewed published papers on the amount of heat that is generated. We systematically searched English language studies published between January 2000 and February 2014 on MEDLINE/PubMed and found 41 articles, of which 27 related to an increase in temperature during preparation of the site. We found only basic research with a low level of evidence. Most of the studies were in vitro, and osteotomies were usually made in non-vital bone from cows or pigs. To measure heat in real time, thermocouples were used in 18 studies and infrared thermographs in 7. Three studies reported the use of immunohistochemical analysis to investigate immediate viability of cells. The highest temperature measured was 64.4 °C and the lowest 28.4 °C. Drill wear was reported after preparation of 50 sites, and there was a significant increase in temperature and a small change in the physiological balance of the proteins in the bone cells. Differences in the study designs meant that meta-analysis was not appropriate. For future work, we recommend the use of standard variables: an axial load of 2 kg, drilling speed of 1500 rpm, irrigation, standard artificial bone blocks, and the use of infrared thermography.

Keywords: Heat generation; Implant site preparation; Irrigation methods; Osseous models; Infrared thermography; Thermocouple

Introduction

Heat that is released during the preparation and insertion of implants could have consequences for the bone, and it has already been shown that the extent of the necrotic zone around the preparation site is proportional to the amount of heat generated.[1] Repeated use causes drills to wear and reduces their efficiency, and the temperature increases each time a bur is used.[2] Other variables may also affect their cutting ability and the amount of heat generated. Preparation of the site is a complex process and the shape, sharpness, and speed of the drill, applied axial load, and the density of the bone all have an effect.[3–7]

To our knowledge, the only review of this subject was published in 1999 by Tehemar who tried to identify all the factors that influence the amount of heat generated when bone is drilled.[8] However, questions remain about the optimal design of the drill, the best type of irrigation, the degree of heat generated depending on the bone density, and the speed of the drill. Our aim was to find out whether these could now be answered.

Material and methods

We searched the MEDLINE/PubMed database for articles published between January 2000 and February 2014 using

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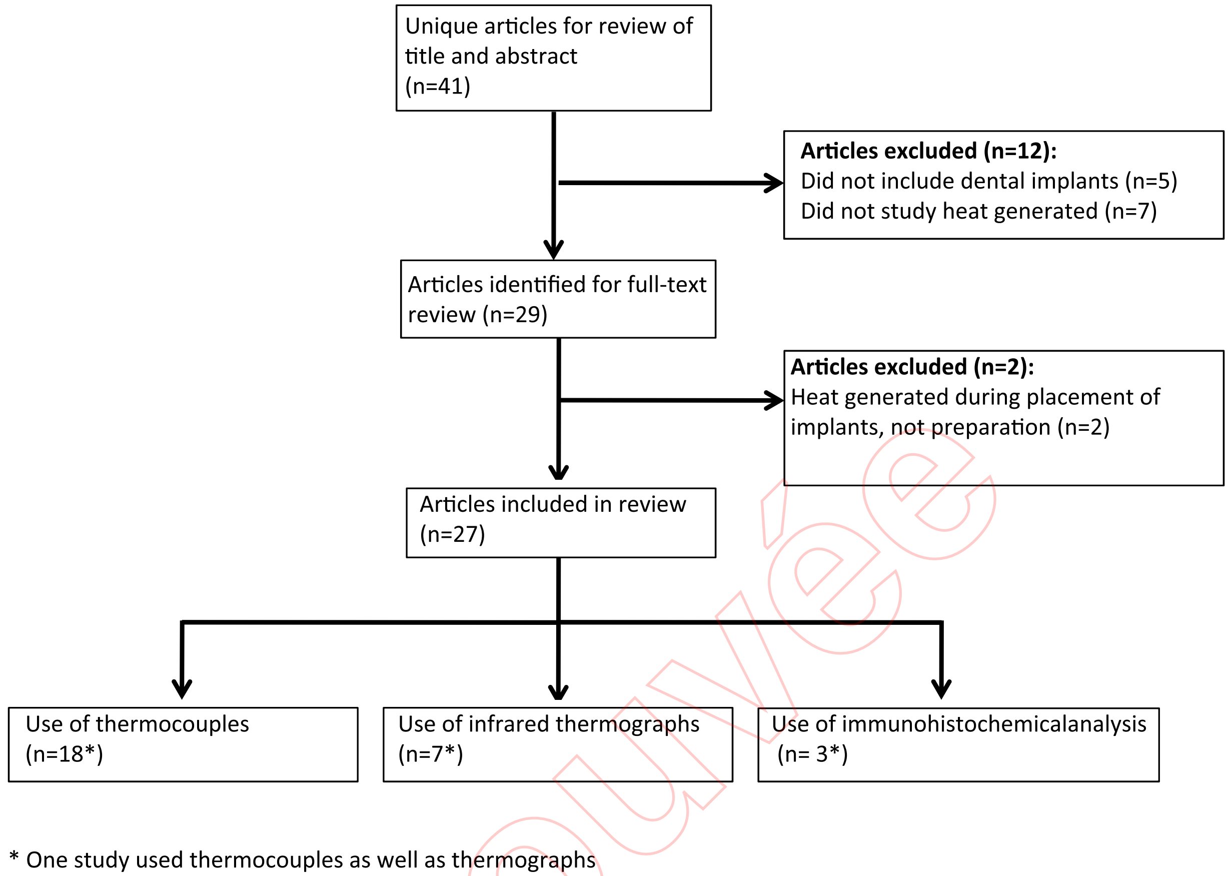

Fig. 1. Search results.

different combinations of the keywords implant and; heat or; temperature and; osteotomies or; drill. A total of 41 were found. After initial screening of titles and abstracts, the text was studied in more detail. Fourteen articles were excluded because they did not investigate preparation of the implant bed. Finally, 27 studies remained and were included in this review (Fig. 1).

Results

To assess the amount of heat generated in real time, thermocouples were used in 18 studies (Table 1) and infrared thermographs in 7 (Table 2). Three studies investigated immediate cell viability using immunohistochemical analysis (Table 3). Drill wear was the focus of 10 investigations.

Effects of heat on bony regeneration

Depending on the amount of heat generated, bony turnover can be impaired by hyperaemia, necrosis, fibrosis, osteocytic degeneration, and increased osteoclastic activity.[8] Eriksson and Albrektsson investigated the histological effects of heat on bone.[9–11] In animal studies they used a fixed thermal chamber to monitor the metabolism of bone at different temperatures, and they made a distinction between acute and chronic effects. Arterial and venous hyperaemia were observed during acute effects, and blood-flow stopped in different parts of the capillary. There were no connective tissue reactions. A chronic effect was characterised by recirculation of the capillaries after 4 days and was associated with slight elongation of the vessels. Fat cells began to resorb 2 days after the thermal increase and continued to do so for 14 days. They changed in shape and colour then new fat cells were produced. At the third week about 30% of the bone had resorbed. A high temperature for a short duration (50 °C for 1 minute) had almost the same effect as a low temperature for a long duration (47 °C for 5 minutes). A low temperature for a short duration (47 °C for 1 minute) reduced bony resorption by about 10%. The authors concluded that the critical temperature, which can lead to irreversible damage to the bone's structure, is about 47 °C for one minute. At lower temperatures damage is not anticipated. Therefore, to enable the successful osseointegration of endosseous implants, low temperatures are required during preparation of the recipient site.

Study models

There is no standard study model for investigations into the preparation of implant beds. Different osseous models based

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Table 1
In vitro studies of heat measured using thermocouples.

First author and reference	Subject	Implant system	Temperature range (°C)	Irrigation	Speed (rpm)	Axial load	Bone model	Sensor	No. of drills for each test	Size of final osteotomy (mm)		Depth recorded (mm)	Distance to final drill (mm)	Thermocouple		Element isolation technique
										Diameter	Depth			No.	Size	
Allsobrooks[17]	Drill wear	Straumann Nobel Biocare Neoss	20–27.7	External 0.9% saline	800 2000 2000	1.5	Bovine rib	k type Digi-Sense DualLogR Model 91100-50 (Cole-Parmer, Vernon Hills, USA)	50	3.5 3.4 3.4	6 10 12	4.0 12.0	1.0	2	1.5	–
Bulloch[18]	Single compared with multiple drills, drill guide	Straumann	14.77–26.39	External Water	2100	2	Bovine femur	k type (Omega Engineering)	90	3.5 4.2	–	8.0	1.0	2	0.8	Silicon
Chacon[13]	Drill design Sterilisation	–	37–64.4	External, 0.9% saline 40mL/min	2500	2.4	Bovine femur	k type Model 5SRTC-TT-K-30-36 (Chromega-Alomega, Omega Engineering, Stamfort, USA)	25	4.0 4.2 4.2	–	15.0	0.5	1	2.3	0.9% saline Orthodontic wax
Ercoli[12]	Drill wear and design Cortical bone	3i Straumann Lifecore Nobel Biocare (Brånemark) Implamed Paragon Nobel Biocare (Steri-Oss)	28.4–31.9 Increase 1.4–2.5	External, 90mL/min	1500	37 (N)	Bovine rib	Teflon insulated (Chromega-Alomega, Omega Engineering, Stamfort, USA)	100	3 2.8 3 3 3 3.2 3.2 5	15	5.0 15.0	1.0	2	1.5	Silicon
Gehrke[26]	Single compared with multiple drills Irrigation	Straumann Nobel Biocare IDAll	Group 1: 22.2–32.1 Group 2: 18.9–26.8	Group 1: no Group 2: external 50mL/min	800 600 500 2000 800 800 1500	2	Synthetic bone	k type, Mod. TP-01 (Luntron Electronics Co Inc, Coopersberg, USA)	20	4.1 4.3 4.2	12 13	2.0	1.0	1	1.0	–
Harder[19]	Drill material	Komet	Increase (base 37) 0.6–3.9	External 50mL/min	1200	1 0.5	Bovine rib	t type, Cu-Ni	10	1.2	13	4.0 8.0 12.0	0.5	3	0.2	Intravenous cannula Composite
Jeong[28]	Drill guide Flap compared with flapless surgery	–	Group 1: Min. 29.5, 32.6 Group 2: Min. 29.5, 32.6	External 40mL/min	–	–	Resin mandible	k type (Yokogawa, Tokyo, Japan)	–	4.3	–	3.0 6.0	0.5	2	1.0	Bone wax
Koo[42]	Drill wear and material Irrigation	Komet Dentium Astra Tech	Group 1: 34.4–64.7 Group 2: 29.5–31.3	Group 1: no Group 2: external 90mL/min	3000	0.75 0.5	Bovine scapula	k type, Model TT-K-40-25 (Chromega-Alomega, Omega Engineering, Stamfort, USA)	200	4.2 4.3	11	4.0 10.0	0.2	2	0.9	Sticky wax
Misic[23]	Bone drilling compared with bone condensing	Straumann	Increase (base 29) 0.6–4.4	Group 1: no Group 2: external 0.9% saline 50mL/min	600	–	Porcine rib	Energyx, Nis, Serbia	24	3.5	10	1.0 5.0 10.0	0.5	3	0.5	Bone wax
Misir[3]	Drill guide Irrigation	Straumann Zimmer	Group 1: max 31.9 Group 2: max.36.1 Group 3: max 37.9 Group 4: max 30.2	Group 1: external Group 2: external and internal	1500	2.0	Bovine femur	k type, Teflon insulated Model 5SRTC-TT-KI-36, (Chromega-Alomega, Omega Engineering, Manchester, UK)	50	4.2 4.3	–	3.0 6.0 9.0	1.0	3	–	–

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Table 1 (*Continued*)

First author and reference	Subject	Implant system	Temperature range (°C)	Irrigation	Speed (rpm)	Axial load	Bone model	Sensor	No. of drills for each test	Size of final osteotomy (mm)		Depth recorded (mm)	Distance to final drill (mm)	Thermocouple		Element isolation technique
										Diameter	Depth			No.	Size	
Oliveira[14]	Drill material	MIS	Increase 0.79–2.24	External 50mL/min	800	–	Bovine rib	k type	50	1.9	8 10	8.0 10.0	1.5	1	1.0	–
Quaranta[24]	Bone condensing Bone quality	Winsix Biosaf	36.02–36.70	No	–	–	Porcine rib	t type (BK Precisione, Taiwan)	25	4.5	9	2.0 5.0 9.0	1	3	1.5	Sticky wax
Rashad[15]	Piezosurgery compared with conventional drilling	Straumann Mectron NSK	Increase (drilling) 1.4–2.7 Increase (ultrasonic) 5.2–9.7	External 20mL/min 50mL/min 80mL/min	–	5 8 15 20	Bovine rib	Teflon insulated Ni-Cr-Fe-alloy	10	3.5	–	1.5 7.0	1.0	2	1.6	–
Stelzle[5]	Drill load Comparison between piezosurgery, conventional drilling, and trephine drill	Tikom Mectron	Piezosurgery 35.2–48.6 Spiral bur 30.2–45.5 Trephine bur 36.2–43.9	External 50mL/min	20 000	0.0–0.1 0.1–0.2 0.2–0.3 0.3–0.4 0.4–0.5 0.5–0.7 0.7–0.8 0.8–0.9 0.9–1.0	Porcine head	Ni-Cr-NI Model GTT 15150 (Greisinger, Regenstauf, Germany)	12	3.0	6	6.0	2.0	1	1.5	Silicon
Strbac[21]	Drilling depth Drill diameter Irrigation	Nobel Biocare	Increase: Without irrigation 6.11–29.87 External irrigation 0.5–28.47 Internal irrigation 0.4–25.86 Combined irrigation 0.27–25.68	0.9% saline External Internal Combined 50mL/min	800	–	Artificial bovine bone, 1800.35/1300.14 Composite (BoneSim, Newaygo, USA)	Multichannel SHT, 7 NTC type Model GA10KM3499J15 (Measurement Specialties, Hampton, USA)	80	2.0 3.5 4.3 5.0	10 16	2.0 4.0 8.0 10.0 11.0 13.0 16.0	1.02.0	2	1,5	Compound (HTCP20S Electrolube, Leicester, UK)
Strbac[25]	Drilling and withdrawing-relation Drilling depth Drill diameter Irrigation	Nobel Biocare	Increase: Without irrigation 17.34–45.46 External irrigation 8.07–45.95 Internal irrigation 6.55–44.43 Combined irrigation 1.52–42.01	0.9% saline External Internal Combined 50mL/min	800	–	Artificial bovine bone, 1800.35/1300.14 Composite, (BoneSim, Newaygo, USA)	Multichannel SHT, 7 NTC type Model GA10KM3499J15 (Measurement Specialties, Hampton, USA)	80	2.0 3.5	10 16	2.0 4.0 8.0 10.0 11.0 13.0 16.0	1.0	1	1.5	Compound (HTCP20S, Electrolube, Leicester, UK)
Strbac[20]	Drilling depth Drill diameter Irrigation	Nobel Biocare	Increase: Without irrigation 2.20–8.01 External irrigation 0.55–2.60 Internal irrigation 0.48–1.48 Combined irrigation 0.51–1.51	0.9% saline, External Internal Combined 50mL/min	800	–	Bovine rib	Multichannel SHT, 7 NTC type Model GA10KM3499J15 (Measurement Specialties, Hampton, USA)	80	2.0 3.5 4.3 5.0	10 16	2.0 4.0 8.0 10.0 11.0 13.0 16.0	1.02.0	2	1.5	Compound (HTCP20S, Electrolube, Leicester, UK)
Sumer[16]	Drill material	Thommen Medical	Stainless steel drill: 32.15–37.5 Ceramic drill: 34.49–36.72	–	1500	2.0	Bovine femur	k type, Teflon insulated Model 5SRTC-TT-KI-36 (Chromega-Alomega, Omega Engineering, Manchester, UK)	50	4.3	–	3.0 6.0 9.0	–	3	1.0	Silicon

Table 2
In vitro studies of heat assessment using infrared thermal imager.

First author and reference	Theme	Implant system	Temperature range (°C)	Irrigation	Speed (rpm)	Axial load (kg)	Bone model	No. of drills for each test	Size of final osteotomy (mm)		Thermoimaging system
									Diameter	Depth	
Benington[6]	Irrigation Diameter	3i	Increase: Internal irrigation: 0–3.20 External irrigation: 0.04–3.10	Group 1: Internal Group 2: External 0.9% saline	2500	1 .7	Bovine mandible	12 6	2.0 3.25	–	Agema Thermvision 900 (Agema Danderyd, Sweden)
Bulloch[18]	Single compared with multiple drills Drill guide	Straumann	Increase 1.0–2.82	External Water	2100	2	Bovine femur	90	3.5 4.2	–	Fluke 62 Mini IR Thermometer
Kim[22]	Drill speed	Bicon Nobel Biocare Osstem	Increase (base 31) 1.57–2.46	No	1200 50	10	Porcine rib	10	2.0 3.0	–	IRI 1001 system (Infrared Integrated Systems Ltd)
Oh[27]	Drill design, Drilling and withdrawing-relation	Osstem	Increase (base 30) 2.27–8.90	No	1500	4 (N)	Synthetic bone (Sawbone, Pacific Research Lab Inc, Vashon, USA)	20	3.60 3.45 3.25 3.10	15 .0	IRI 1001 (E Irisys, Northampton, UK)
Pires[38]	Drill material	Nobel Biocare Thommen Medical	Group 1: min 28.7 Group 2: min 28.4	External 0.9% saline	800	0 .5	Swine rib	80	2.0	10 .0	RAYGPSCLW, (Raytek)
Scarano[2]	Bur wear	Bone System	–	External 0.9% saline	500	–	Bovine rib	0 30 60 90 120	3.5	10 .5	FLIR SC3000 QWIP (Flir Systems, Daderyd, Sweden)
Scarano[4]	Drill design	Bone System	Group 1: 32.4 Group 2: 30.1	External 0.9% saline 50mL/min	800	–	Bovine femur	18	3.7	–	FLIR SC3000 QWIP (Flir Systems, Daderyd, Sweden)

Table 3
Studies of viability of bone cells after implant osteotomy.

First author and reference	Theme	Implant system	Expressions	Irrigation	Speed (rpm)	Axial load (kg)	Bone model	No. of drills for each test	Size of final osteotomy (mm)		Immunohistochemical analysis
									Diameter	Depth	
Carvalho[11]	Drill wear	Conexao	OPG RANKL OC	External 0.9% saline	1200	–	White rabbit tibia (New Zealand)	10	3.15	4.0	Decalcification: 5% EDTA (3 months) Detection: Immunoperoxidase method (primary antibodies of OPG, RNAKL, OC) Immunoreaction: DAB
dos Santos[31]	Guided surgery	Conexao	OPG RANKL Cas-3	External 0.9% sodium chloride solution	1600	–	White rabbit tibia (New Zealand)	5	3.15	4.0	Decalcification: 5% EDTA (3 months) Detection: Immunoperoxidase method (primary antibodies of OPG, RNAKL, Cas-3) Immunoreaction: DAB
Queiroz[29]	Drill wear	Dérig	OPG RANKL OC	External 0.9% sodium chloride solution	1600	–	White rabbit tibia (New Zealand)	5	3.15	4.0	Decalcification: 5% EDTA (3 months) Detection: Immunoperoxidase method (primary antibodies of OPG, RNAKL, OC) Immunoreaction: DAB

OPG: Osteoprotegerin; RANKL: Receptor activator of NF-κB ligand; OC: Osteocalcin; Cas-3: Caspase 3; DAB: Diaminobenzidine; EDTA: Ethylenediaminetetraacetic acid.

on cadaveric bone blocks from cows or pigs were used to record temperatures during drilling.[2,12–25] Three studies used synthetic blocks,[21,26,27] and one a resin model.[28] In 3 animal studies, immunohistochemical analysis was done to check the viability of bone cells.[29–31] The work of Strbac et al. to achieve standardisation and reproducibility of test results using a new standard bone model is a positive step.[21] Use of artificially manufactured bovine bone provided equal vertical and horizontal variables. It allowed a standardised ratio between cortical and cancellous bone, and a bone density that should correspond to clinical conditions in human bone (type 2 according to the Lekholm and Zarb classification[32]). They reported that this manufactured bone provides analogue thermal conductivity to human bone (0.3–0.4W/m/K) so changes in temperature could be comparable.[33,34] Using this model it is possible to standardise the output variables.

Currently, to our knowledge only 2 methods have been used to record the heat generated in real time. Thermocouples, which enable direct measurement,[3,5,7,13,15–18,23,24,26,35] were first reported in implant dentistry by Horch and Keiditsch.[36] Infrared thermography provides an indirect estimate,[4,18,22,27] and measurements were first described by D'Hodet et al.[37] Although thermocouple technology is well established, studies on its use are still not uniform (Table 1), and there are variations in the distance to the final cut (between 0.5 and 2 mm), configuration of the elements (from mono to tripod), and depths and numbers in the vertical dimension (monochannel and multichannel). Another problem is the ability only to detect spot temperatures. The technology does not enable production of an overall thermal profile or measurement of heat that has leaked. This problem does not exist with infrared technology, which is described as being more accurate with a lower probability of error.[4]

Recent studies have investigated the wear of the drill itself.[2,12–14,17,29,30,38] Descriptive analyses have been done using scanning electron microscopy, and mechanical studies have been based on the electrical power from the torque and tension of the drill. The objective of these studies was to measure the durability of twist drills after multiple uses and the effect on the bone.

Factors that influence the amount of heat generated during preparation of the implant bed

Different factors affect the heat generated during drilling at the implant site. They include the operator (pressure, status, movement, speed, and duration of drilling), manufacturer (design and sharpness of the drill, irrigation system, and implant system), site (cortical thickness, condition of the site, and depth drilled), and patient (age and bone density).[8] Some factors influence each other and others independently and directly affect the temperature. Fig. 2 is modified according

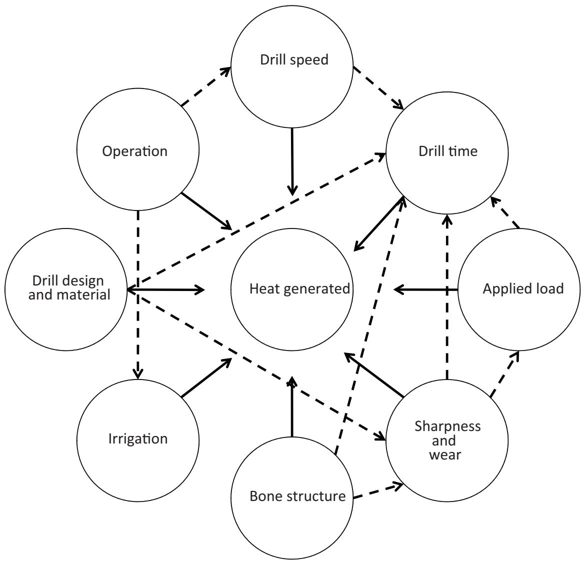

Fig. 2. Factors that interact during drilling of the implant site.

to Hout[39] and is a simplified presentation of the interaction of various factors.

Diameter of the drill

Strbac et al. proved in 3 studies that the thermal increase is inversely proportional to the diameter of the burs.[20,21,25] They used a real-time model with 14 temperature sensors (2 thermoprobes with 7 sensors each) at defined depths and predefined distances of 1 and 2 mm from the final cut.[20,21] During drilling with a supply of coolant the 2 mm diameter twist drills reached higher temperatures than the 3.5 mm diameter conical implant drills. In another study they investigated the heat generated during preparation of the implant site when the diameters of the drills were increased in conjunction with other factors.[21] First, a 2 mm diameter twist drill was used followed by conical drills with diameters of 3.5, 4.3, and 5 mm. Real-time recording showed that, independent of irrigation, a 2 mm diameter drill caused significantly higher temperatures than sequential drills with conical burs.

Design of the drill

The drill is usually the same shape as the implant. However, some manufacturers undercut the base of the implant to achieve better primary stability. The implant bed is usually prepared using twist or triflute drills.[40] Cordioli and Majzoub reported that a 4 mm diameter triflute drill generated less heat than 2 and 3 mm twist, or 3.3 mm triflute drills. They concluded that the shape and design of triflute burs contribute to the dissipation of heat during drilling.[41] Oh et al. evaluated the heat produced by different designs of drill.[27] They modified conventional triflute drills by reducing the diameter and setting the lateral cutting surface, and used an unmodified triflute drill as control. The results showed that the mean change in temperature for all combinations of modified drills was significantly smaller than for the control, which suggests that a reduction in the area of contact between the drill and bone reduces the amount of heat produced.

Scarano et al. also investigated the shape of drills.[4] They quantified temperature changes in the cortical bone and the apical portion of the drill during preparation of the implant site with a cylindrical drill with triple twist and a conical drill with quadruple twist. Differences in mean (SD) temperatures in the bone (cylindrical: 31.2 (0.5) °C compared with conical: 29.1 (0.6) °C) and in the apical portion of the drill (cylindrical: 32.1 (0.7) °C compared with conical: 29.6 (0.6) °C) were significant. They concluded that the temperature generated in the apical part of the drill seemed to correlate with its shape.

Drill material

Several authors have investigated the heat generated by drills made of different materials such as stainless steel or zirconium coated with steel, titanium nitride, tungsten carbide carbon, or different ceramics.[12,14,16,19,42] Sumer et al. compared the heat generated by stainless steel and ceramic drills at depths of 3, 6, and 9 mm.[16] The difference was significant only at a depth of 3 mm (stainless steel 32.15 °C, ceramic 34.49 °C). They concluded that although more heat was generated in the superficial part of a cavity when the ceramic drill was used, the material of the drill relative to the total hole created did not correlate with the temperature. This was also confirmed by Koo et al.[42] In their comparison between titanium nitride-coated and tungsten carbide carbon-coated metal drills, and zirconia ceramic burs, there were no differences in wear of the drill. On the other hand, Oliveira et al. found that the material (ceramic and stainless steel) has a significant influence on the overall heat produced by drilling.[14] However, the mean (SD) increase in temperature for up to 50 uses, which was 1.35 (1.151) °C for the ceramic drill and 1.64 (1.111) °C for the stainless steel drill, should be regarded as low.

Harder et al. used different drill materials and methods of cooling to evaluate the heat generated when drilling in bone.[19] They tested steel and external cooling; steel and internal cooling; steel coated with zirconium nitride and external cooling; and zirconium oxide and external cooling, and compared the results. They found that differences in the heat generated by different drill materials were not significant.

Sharpness and wear of the drill

The sharpness of the bur is directly related to the number of times used, pressure applied, sterilisation technique, density of the bone, construction material, and surface treatment. The waste of drills used for dental implant surgery was the focus in recent studies. Until now, scanning electron microscopy (SEM) has been used to analyse wear of the drill,[2,12,14,17,29,30,38] and qualitative analysis of bony healing has been done immunohistochemically.[2,29–31] SEM has shown small defects on new drills[38] and a high correlation between the amount of damage and number of uses has been seen. After 50 preparations the surface was corroded and degraded, and the plastic was deformed, but the differences in

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temperature were not significant. Repeated use of a bur does not raise the bony temperature over a critical level.[14,17] Only Scarano et al. reported on higher temperatures with more use.[2] Investigations on bony healing in rabbit tibias found no association between the number of times a drill was used and bony healing. A physiological balance of OPG (osteoprotegerin) and RANKL (receptor activator of NF-κB ligand) was given in up to 50 procedures. Later, higher immunolabelling of all proteins was measured and there was a proportional relation between the expression of caspase 3 and the number of times a drill was used (Table 3).[11,29,31]

Drill load

Many authors have investigated the heat generated at different loads when a conventional drill is used.[43–45] Rashad et al. found that increased axial load (5, 8, 15, and 20 N) had no effect on the heat produced during conventional drilling in cortical and cancellous bone.[15] In their comparison between standard burs and 2 different ultrasonic devices, a significant rise in temperature was found, but no association between temperature and pressure was reported for piezosurgery. Stelzle et al. focused on how load affected the heat produced in hard tissue. They compared the amount of heat generated when a spiral bur, a trephine bur, and piezoelectric surgery was used at various loads between 0 and 1000 g.[5] The temperature increased as the pressure increased when piezoelectric surgery and the trephine bur were used, but with a conventional drill the temperature decreased at a load of 500 g. The maximum temperature reached using the conventional drill with a load of 400–500 g was about 45.5 °C; for piezosurgery with a load of 900–1000 g it was about 48.6 °C, and for the trephine bur it was 43.9 °C. At loads of 900–1000 g, histomorphometric examination found maximum alterations at 200.7 μm for piezoelectric surgery and 154.1 μm for 700–800 g for the trephine drill. At loads of 400–500 g there was an alteration of 166.0 μm with a conventional drill. To avoid thermal damage during preparation of the implant site, they proposed a maximum load of 100–400 g for piezosurgery, 100–200 g and 500–1000 g for the spiral drill, and 100–600 g for the trephine bur.

Irrigation

Cooling can be internal or external, and their simultaneous use and the volume or temperature of the solution can vary. Benington et al. investigated the heat generated using an external and an internal irrigation system.[6] They found a difference of about 0.1 °C for 2 mm twist drills and about 0.28 °C for 3.25 mm drills, and concluded that the clinical benefit of using the more expensive internal irrigation system could not be justified. Strbac et al. also examined the temperatures reached when combined internal and external irrigation was used, and when there was no irrigation.[21] In contrast to Benington et al., they found that the highest mean temperature was reached without any irrigation (29.87 °C), followed by external (28.47 °C) and internal irrigation (25.86 °C). Combined (25.68 °C) was close to internal irrigation. Based on these results, internal and combined cooling was superior to external irrigation particularly for deep cavities. Harder et al., who investigated the heat produced at different depths, supported this statement and found significant differences between internal and external cooling groups.[19] The highest temperature by pilot drill was associated with external cooling (about 3.7 °C) in the depth of 4 mm. The lowest temperatures for internal system were found at a depth of 8 mm with internal cooling (about 0.6 °C). The lowest temperatures that were found at a depth of 12 mm was 1.1 °C for external, and 0.8 °C for internal cooling. The different results could be explained by the study design, as Benington et al. used the thermograph[6] and Harder et al. used thermocouples.[19]

Sener at al also recognised that temperatures were lower in the base of the cavity.[34] They compared drilling with and without the use of saline solution at 25 °C and 10 °C at depths of 3, 7, and 12 mm. The mean temperature without irrigation was 41.6, 39.0, and 37.7 °C; with saline solution at 25 °C it was about 36.9, 34.7, and 32.1 °C; and with irrigation at 10 °C it was about 36.2, 33.7 and 36.9 °C. All measurements using saline solution were below body temperature, but the maximum temperatures without irrigation reached values of about 50.9, 47.4, and 38.1 °C. They concluded that external irrigation at room temperature could provide sufficient cooling during drilling. Rashad et al. examined irrigation volumes of 20, 50, and 80 mL/minute and found a mean increase in temperature of between 1.4 and 2.9 °C. They therefore decided that for conventional drilling, a higher volume was not associated with a reduction in temperature.[15]

Operation

Drilling

Bone can be drilled in a single procedure or in gradual steps. Eriksson and Adell found that sequential preparation was more gentle for the bone because drilling in several steps removed a small quantity of cortical bone each time.[46] Gehrke et al. measured the heat produced by drilling with a single 4.2 mm bur, and sets of graded burs for 4.1 and 4.3 mm implants.[26] The graded burs for 4.3 mm implants yielded significantly higher temperatures and they concluded that the single step technique did not generate more heat than conventional multiple sequence drilling. Bulloch et al. confirmed these results.[18] For diameters of 3.5 and 4.2 mm, a comparison between sequential drilling and use of a single bur showed no significant difference in temperature.

Guided surgery

Misir et al. evaluated the influence of surgical drill guides on the amount of heat generated at depths of 3, 6, and 9 mm with and without the use of guides.[3] The mean maximum temperatures were higher when a guide splint was used, and the highest (about 39.8 °C) was found at a depth of 9 mm. In contrast, Bulloch et al. did not find a significant mean maximum temperature.[18] Jeong et al. also found no differences in the temperature of the drill when they compared placement of an implant without raising a flap with placement using conventional drilling when a flap was raised.[28]

Bone condensing

For better primary stability of implants, the bone should be displaced laterally and not removed during preparation of the implant bed. In an in vitro study, Misic et al. investigated the temperature changes in type 4 bone using bone condensing and drilling techniques to prepare the implant site.[23] Thermocouples were used to measure changes in temperature at depths of 1, 5, and 10 mm at a distance of 0.5 mm from final osteotomy. During bone condensing, the mean rise in temperature continuously decreased as the depth increased, but during drilling it increased to a depth of 5 mm and then decreased continuously. Bone condensation therefore generates significantly less heat.

Piezosurgery

Rashad et al. studied the heat generated when piezosurgery was used to cut bone.[15] They compared 2 different ultrasonic devices with a conventional drilling system in cancellous and cortical bone. Both piezoelectric systems produced more heat than drilling, and in 5 cases the critical level of 47 °C was exceeded, even with irrigation. However, in a previous study Harder et al.[47] reported different results. A possible explanation was a lower irrigation volume in the Rashad study. Also, Stelzle et al. found that the average processing time for both piezoelectric devices was significantly longer.[5] Piezosurgery yielded the highest mean temperature (48.6 °C), and histomorphometric analysis showed the greatest thermal effects at about 200.7 μm. Although piezoelectric surgery is meant to be a gentle method of cutting bone, both sets of authors found that it generated higher temperatures, was more time-consuming, and was safe only with sufficient cooling.

Drilling speed

For many years, the ideal instruments for preparation of an implant site were considered to be high-torque, low-speed (1500–2000 rpm) handpieces.[46] Kim et al. used infrared thermography to compare the temperature change of a low-speed system (50 rpm) with 2 conventional systems (1200 rpm).[22] The lowest and highest increases in temperature were about 1.57 °C and 2.46 °C for conventional drilling and about 1.67 °C and 1.72 °C for the low speed drill. The difference was not significant, and the bone was not over-heated at 50 rpm without irrigation.

Drilling time

The increase in temperature is directly proportional to the duration of drilling and depends on various factors.[41] Kim et al. showed that at lower speeds drilling takes longer but does not increase the amount of heat generated.[22] Stelzle et al. investigated applied load in 3 systems (piezosurgery, spiral bur, trephine bur) and found that the time required to prepare the bone continuously decreased with the load.[5] The spiral bur took the least time (5.9 seconds), followed by the trephine bur (7.3 seconds); piezosurgery took 19.5 seconds. The increase in temperature seems to correlate with the drilling time. At maximum load, the lowest temperature measured was with the spiral bur (40.3 °C), followed by the trephine bur (43.9 °C) and piezoelectric surgery (48.6 °C). The outcome was similar to that described by Rashad et al.[15]

Bone

Thermal conductivity varies between cortical and cancellous bone, probably because of the different rate of vascular penetration (cancellous bone about 0.5 mm/day, cortical bone about 0.05 mm/day).[48] In a histological assessment of the effect of osteotomy in both types of bone, Stelzle et al. found the highest temperatures in the cortical areas.[5] For piezosurgery and the trephine bur, increased applied load correlated with increased alterations in tissue caused by heat, but this was not so for the conventional spiral bur.

Discussion

Direct comparison of the studies is difficult because of their different designs. This is attributed in part to the study model, the method used to measure the heat generated, or the variety of surgical tools used. For example, the axial load varied between 0.1 and 10 kg, even if it was not the aim of the investigation, and speeds varied between 500 and 2500 rpm.

Even the bone models, particularly the studies on porcine and bovine bone, must be questioned because they contain a lot of cancellous bone, which is easier to drill. Misic et al.[23] described porcine ribs using the classification published by Lekholm and Zarb[32] as D4, and Quaranta et al.[24] also described the quality of the bone as D3–D4. Strbac et al.[21] and Gehrke et al.[26] used artificially manufactured bone based on polyurethane, and these approaches are valuable as good reproducibility means that the materials are less sensitive to error.

To date, the optimal geometric design for a drill that will minimise the amount of heat generated has not been found. It is clear that a reduction in the diameter and the lateral cutting surface has a positive effect,[27] and that a conical design seems advantageous, but the material of the bur is less important.[4,19]

New information about the effect of heat on bony healing has come to light. Studies have shown that cell viability was preserved after repeated use of drills. The expression of osteoprotegerin, caspase 3 or RANKL varied after 50 procedures,[29,31] which seems to limit the frequency of their use. Further studies are necessary to find possible associations between cell viability, preparation of the implant site, and the temperature generated.

Great advances have been made in irrigation techniques. Differences between internal and external irrigation were not significant, but with increasing depth, internal or combined cooling seemed to be more effective than external irrigation. However, use of internal irrigation needs to be questioned because it is expensive and the reductions in temperature are relatively small. Surprisingly, temperatures above 47 °C are rarely generated when drilling is done without irrigation. Statements about the benefit of cooling as a function of depth are contradictory and require further investigation.

Many investigations use non-vital cancellous porcine or bovine bone so the results are limited in relation to humans and clinical practice. Only one study used polyurethane blocks that corresponded to D1 bone quality. There are considerable differences in the bone models reported. Gehrke et al.[26] and Sumer et al.[16] used stainless steel drills of similar diameters (4.2 and 4.3 mm) with irrigation, a speed of 1500 rpm and an applied load of 2 kg. Both used a thermocouple to detect the temperature. Mean temperatures of between 32.12 and 37.4 °C were generated in bovine bone models, but in a foam block model the temperature was 22.2 °C.[16,26] The wide discrepancy limits the translational value, and more studies are needed to find the ideal model.

Conclusion

Much research has been done on dental implants but less has been done on preparation of the implant site, and further studies are needed. To achieve better comparability and to maximise the translational potential of such research, we recommend the use of standard variables: an axial load of 2 kg, drilling speed of 1500 rpm, irrigation, standard artificial bone blocks, and the use of infrared thermography.

Conflict of interest

We have no conflicts of interest.

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Ethics statement/confirmation of patient permission

This is a review about current literature without any patient contact. Consent for publication is not necessary.

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