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REVIEW ARTICLE

Heat Generated by Dental Implant Drills During Osteotomy—A Review

Heat Generated by Dental Implant Drills

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Abstract *Statementof problem*: Osseointegration is the more stable situation and results in a high success rate of dental implants. Heat generation during rotary cutting is one of the important factors influencing the development of osseointegration. *Purpose*: To assess the various factors related to implant drills responsible for heat generation during osteotomy. *Materials and Methods*: To identify suitable literature, an electronic search was performed using Medline and Pubmed database. Articles published in between 1960 to February 2013 were searched. The search is focused on heat generated by dental implant drills during osteotomy. Various factors related to implant drill such effect of number of blades; drill design, drill fatigue, drill speed and force applied during osteotomies which were responsible for heat generation were reviewed. Titles and abstracts were screened, and literature that fulfilled the inclusion criteria was selected for a full-text reading. *Results*: The initial literature search resulted in 299 articles out of which only 70 articles fulfils the inclusion criteria and were included in this systematic review. Many factors related to implant drill responsible for heat generation were found. Successful preparation of an implant cavity with minimal damage to the surrounding bone depends on the avoidance of excessive temperature generation during surgical drilling. *Conclusion*: The relationship between heat generated and implant drilling osteotomy is multifactorial in nature and its complexity has not been fully studied. Lack of scientific knowledge regarding this issue still exists. Further studies should be conducted to determine the various factors which generate less heat while osteotomy such as ideal ratio of force and speed in vivo, exact time to replace a drill, ideal drill design, irrigation system, drill-bone contact area.

Keywords Dental implants osteotomy · Heat generation · Drill cooling · Implant drill design · Surface contact area

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Introduction

Osseointegration has been defined as the direct bone support of the implant body without encapsulation by connective tissue at the optical microscopic level [1]. At present, there is a general agreement that osseointegration is the more stable situation and results in a high success rate for up to 15 years [2]. Various factors affecting osseointegration are implant design, chemical composition, topography of implant surface, material and shape of implant, host bone bed and its intrinsic healing potential, loading conditions, stability, use adjuvant treatments, pharmacological agents and heat generation during osteotomy [3–8]. The successful use of endosseous implants in dentistry has increased dramatically over the last 20 years. This has resulted from improvements in implant materials, forms, and surfacing, and by the perfection of surgical techniques, supra-structure construction, and postoperative dental hygiene [9]. Osseointegration is regarded as the optimal result [10]. Watzek et al. [11] had reported many factors for the successful healing of implants. Heat generations during rotary cutting are one of the important factors influencing the development of osseointegration [8]. Bone tissues are very susceptible to thermal injury, and the temperature threshold for tissue survival during osteotomy is 47 °C when drilling is maintained for more than 1 min [12, 13]. Heating in excess of this limit could lead to primary failure to achieve osseointegration [14]. The frictional heat generated at the time of surgery will always cause a certain degree of necrosis of the surrounding differentiated and undifferentiated cells, thereby representing a significant risk for failed bone integration [15]. In vitro studies have found that the overall concept of heat generation is considered multifactorial in nature [16], and most reports restrict their investigation to 1 or 2 factors [17–22]. At present, many implant companies do not indicate how many times a drill should be used, thereby hindering the understanding of dentists about the optimal frequency of drill replacement. This could result in greater tissue trauma to the surgical bed, leading to higher rates of implant loss [14]. It is critical for the success of dental implants that minimal heat is generated in the bone during the drilling of the implant sites. This review of literature is highlighting the various drill factors responsible for heat generation and a measure to reduce the same for successful osseointegration of dental implants.

Search Strategy

A broad search of the dental literature in Medline and Pubmed was performed for articles published between 1960 and February 2013. A focus was made on peer-reviewed dental journals. The key words searched were Dental implant osteotomy, Heat generation; Drill cooling, Implant drill design, Surface contact area. The search strategy included the combination of the following terms: "Dental implant drills, speed and force during osteotomy, heat generated by implant drills, external and internal irrigation of dental implant drills, heat generated during osteotomy, effect of heat on osseointegration." Manual searches of the references of all full-text articles and relevant review articles selected from the electronic search were also performed.

Selection Criteria

To determine which studies to include in the present systematic review, the following inclusion criteria were applied. Articles related to heat generation by dental implants drills due to various reasons mentioned above were only included. Both abstract and full text articles were included. Studies not meeting any of the inclusion criteria were excluded from the review. The initial literature search resulted in 299 articles out of which only 70 articles fulfils the inclusion criteria and were included in this systematic review.

A systematic review of available articles from the Medline and Pubmed data base was done to find various implant drill factors that are responsible for heat generation during osteotomy. The review article describes about the materials used to simulate bone and method used to measure heat in various studies, about compact and spongy bone and effect of heat on them. Also describes about role of external and internal irrigation, effect of drill design, drill speed and force applied during osteotomy on heat generation. A synopsis of various studies on heat generation by dental implant drill during osteotomy is given in Table 1.

Factors related to dental implant drills that affect osseointegration
Osteotomy location
Compact bone
Spongy bone
Type of irrigation
External irrigation
Internal irrigation
Number of blades in the drill
Drill design
Drill fatigue
Drill speed during osteotomy
Force/pressure applied during osteotomy

Materials Used to Simulate Bone and Method Used to Measure Heat in Various Studies

A variety of drilling materials have been used in various studies such as in rabbit mandible [36], rabbit tibia [23], pig maxilla and mandible [24], pig rib [8], sheep tibia [25], bovine cortical/medullary bone [20–22, 26, 27], and polymeric material [28].An acetal homopolymer (Delrin Acetal) was used to simulate living maxillofacial bone as the drilled substance [28]. This material has been validated in its elastic similarity to bone with longitudinal (8.99 GPa) and shear (1.76 GPa) stiffnesses [37]. A heat transfer comparison of the bone and delrin showed that ability to resist heat flow (thermal conductivity, k) indicates that bone would be a better promoter of heat conduction (k = 2.0 N/[°C/s]) than the Delrin (k = 0.30 N/[°C/s]) [38].

Various methods were used to measure heat generated during drilling of bone while dental implant placement. One method used to measure temperature is Real-time infrared thermography. The thermograph detects the radiant infrared value of the subject, discriminates distribution of temperature as a visible image, and expresses it by color on a monitor [8, 29]. Other method is during each preparation temperature measurements were made with a shielded thermocouple, and they were recorded on a

Table 1 Synopsis of various studies on heat generation by dental implant drill during osteotomy

Author	Purpose of study	Site of implant placement	Type of temperature assessment/other assessment	Type of drill/ implant system	Study summary	Outcome
Watanabe et al. [8]	The generation of heat that spread in the presence or absence of irrigation	Pig rib	Real time infrared thermography	IMZ, Brånemark, and ITI (F type) implant rotary cutting drills or burs	Measure the distribution of heat to bones and the maximum temperature that developed when cutting bone with drills	Without irrigation, the condition of heat spread in each drill and bur differed according to bur shape and drilling site Maximum heat temperature without irrigation was higher than that with irrigation
Ercoli et al. [14]	The cutting efficiency, durability, heat production and wear of implant drills	Bovine rib	Software program	Nobel Biocare, 3i/ Implant Innovations, Steri-Oss, Paragon, Implamed, Lifecore, and ITI Spade, twist, triflute, and TiN-coated drill designs	Evaluated, under conditions simulating implant placement	Drill design, material, and mechanical properties significantly affect cutting efficiency and durability Implant drills can be used several times without resulting in bone temperatures that are potentially harmful Continuous drilling in deep osteotomies can produce local temperatures that might be harmful to the bone Two 2-mm drills (Nobel Biocare and 3i/Implant Innovations) had mean removal rates significantly greater than the others. The 2-mm twist drill design with a low hardness (Implamed) exhibited plastic deformation at the cutting edge, loss of cutting efficiency, and drill fracture The TiN-coated drills (Steri-Oss and Paragon) showed greater wear and significantly lower removal rates than noncoated drills

Table 1 continued

Author	Purpose of study	Site of implant placement	Type of temperature assessment/other assessment	Type of drill/ implant system	Study summary	Outcome
Cordioli and Majzoub [21]	Irrigation and flute design	In vitro bovine cortical femur bone	Thermocouple	Screw-shaped and cylindrical implants	Thermal changes elicited during drilling and tapping procedures were measured	No statistically significant differences could be found between the maximum temperatures generated when tapping was performed with and without irrigation at both 4- and 8-mm depths The geometry of triflute burs combines cutting efficacy with greater heat dissipation capabilities than twist drills at the drilling depths of 4 and 8 mm
Chacon et al. [22]	Heat generated due to drill geometry and repeated drilling	In vitro bovine femoral cortical bone	Thermocouple	Triple twist drills with a relief angle, triple twist drills without a relief angle, and double twist drills with a relief angle	Intermittent drilling was accomplished at a constant 2.4-kg load and drill speed of 2,500 rpm Heat measurements were recorded out to 25 uses	Light microscopy showed little drill wear even after 25 uses. Increased temperature readings seen in triple twist drills without a relief angle
de Souza Carvalho et al. [23]	Bone heating, immediate bone cell viability, drill wear	Rabbit tibias	Digital themometer	Spear drills and helical drills	Evaluate the influence of reusing high-resistance drills on bone heating, immediate bone cell viability and drill wear	No significant bone heating after drill being reused for 50 times. There were greater thermal changes during drilling with the spear drill than during drilling with helical drills (ratio 3:1)
Sharawy et al. [24]	Heat generated due to drilling speeds	Pig jaw bone	Thermocouples	Internally irrigated systems Steri-Oss and Paragon Externally irrigated systems Branemark and Maestro	Measure the heat generated from three drilling speeds (1,225, 1,667, and 2,500 rpm)	It was concluded that preparing an implant site at 2,500 rpm could decrease the risk of osseous damage. This may decrease the devital zone adjacent to an implant after surgery

Table 1 continued

Author	Purpose of study	Site of implant placement	Type of temperature assessment/other assessment	Type of drill/ implant system	Study summary	Outcome
Haider et al. [25]	Drill cooling with both internal and external irrigation	Sheep tibia bone	Computer-aided histomorphometry	Internally cooled spiral drill and externally cooled rose-head drill	IMZ implant was placed in the diaphysis (compact bone) and metaphysis (spongy bone)	Additional external cooling seems beneficial for any internal cooling, particularly in compact bone Spongy bone apparently tolerates drilling heat better
Brisman [26]	The effect of speed, pressure and time on bone temperature	Bovine femoral bone	Shielded thermocouple	2.00-mm pilot; 2.50-mm spade; and 3.25-mm spade drills of dentsply implant	Drilling was done at speeds of 1,800 and 2,400 rpm and loads of 1.2 and 2.4 kg	Drilling at a low speed of 1,800 rpm and at a minimal load of 1.2 kg produced the same heat as when the drill speed was increased to 2,400 rpm and the load was increased to 2.4 kg Independently increasing either the speed or the load caused an increase in bone temperature in bone
Allsobrook et al. [27]	The effects of multiple usages of dental implant drills on bone temperature	Bovine rib	Thermocouple	ITI (Straumann), NB (Nobel Biocare) and NE (Neoss)	Investigate the effects of multiple usages of dental implant drills and examine the cutting surfaces of these drills	Drills used for up to 50 osteotomies do not appear to elevate bone temperatures to a harmful level. The tungsten carbide-coated bur had the lowest overall drilling temperatures and showed the least surface corrosion and plastic deformation
Harris and Kohles [28]	Effect of mechanical and thermal fatigue on drill performance	An acetal homopolymer	Scanning electron microscope	3i Irrigated Tri-Spade, 3i disposable, Nobel Biocare, Straumann and Lifecore	In this study, peak torque and axial load levels were measured during a drilling procedure	Scanning electron microscopic images revealed minor deformations in the cutting edges of the tri-spade drills following testing
Jun et al. [29]	Implant drill characteristics on bone temperature	Artificial bone block	Infrared thermal imager	Conventional triflute Ø3.6 mm drills were modified	Evaluate the effect of drill–bone contact area on bone temperature	The observations herein suggest that reduction in contact area between the drill and bone reduces heat induction

Table 1 continued

Author	Purpose of study	Site of implant placement	Type of temperature assessment/other assessment	Type of drill/ implant system	Study summary	Outcome
Sener et al. [30]	Irrigation temperature on heat control	Bovine bone	Thermoresistor	Camlogs drill system	Investigated the effectiveness of the temperature of the saline solution used for heat control during drilling	External irrigation at room temperature can provide sufficient cooling during drilling Lower temperature saline was more effective in cooling the bone
Benington et al. [31]	Internal and external irrigation	Bovine bone	Thermogram	2 mm twist drill and a 3.25 mm drill	Compare the temperatures that were generated with external and internal irrigation systems during bone preparation,	No statistical benefit was observed for one irrigant delivery system over the other The clinical benefit of using the more expensive internal irrigation systems is therefore deemed unjustifiable
Sumer et al. [32]	Heat generation during implant drilling	Bovine femoral cortical bone	Thermocouple	Stainless steel and ceramic drills	Compare the heat generated from implant drills. A drill load of 2.0 kg was applied at a speed of 1,500 rpm	More heat was generated in the superficial part of the drilling cavity with the ceramic drill Heat modifications seemed not to be correlated with the drill type, whether stainless steel or ceramic, in the deep aspect of the cavity
Misir et al. [33]	Surgical drill guide and heat generation	Bovine femoral cortical bone	Thermocouple	Surgical drill guides and classical drill procedure	Evaluated the heat generated in bone by two implant drill systems	It was concluded that preparing an implant site with using surgical drill guide generates heat more than classical implant site preparation regardless of the irrigation type
Watanabe et al. [34]	Heat distribution in bone during osteotomy	Pig rib	Real time thermography	Spiral drill, Round bur and Canon drill	The heat distribution during bone preparation with IMZ implant drills and bur	Any drill or bur generates higher heat without irrigation Spiral drill takes the longest time to complete drilling with slow heat rising Round bur and Canon drill take short time to complete drilling with rapid heat rising

Table 1 continued

Author	Purpose of study	Site of implant placement	Type of temperature assessment/other assessment	Type of drill/ implant system	Study summary	Outcome
Iyer et al. [35]	Drill speed and heat production	Rabbit tibia	Thermocouple	700XL carbide burs	Osteotomy preparation at low, intermediate and high speeds	An inverse relationship was observed between drill speed and heat production
Iyer et al. [36]	Drill speed and healing	Rabbit tibia	Histological examination	700XL carbide burs	The rate and quality of healing after drilling osteotomies at the three speeds	In the initial 6 weeks, the rate of healing and quality of new bone formation were higher after high-speed drilling

microprocessor thermometer [22, 24, 26, 27]. In a study thermal quantification was performed with the use of a digital thermometer [23].

Compact Bone Versus Spongy Bone

Successful preparation of an implant cavity with minimal damage to the surrounding bone depends on the avoidance of excessive temperature generation during surgical drilling [21]. Heat generations varies with osteotomy location [8, 20]. Cortical bone is dense and contains little water, so the thermo-conductive rate is higher than in the bone marrow, with relatively rapid conduction of heat. Spongy bone has a lattice structure and contains water and lipids so frictional heat generated in the cylinder wall of spongy bone is unlikely to spread at periphery [8]. Structure and vascularization play an important role in the reaction of bony tissue to the effect of heat. Well supplied with blood vessels, spongy bone dissipates the heat faster and has a greater capacity for regeneration than compact bone, which has a poor blood supply [39–43]. Huiskes R [43] in their study found that the resorption in compact bone (with up to 550 μm) was far more extensive than in spongy bone (maximum 180 μm), which confirms the inferior thermal properties of compact bone. Roberts et al. [44] found a 1,000 μm-wide resorption pattern of damaged peri-implant compact bone. A higher failure rate of dental implant in D1 bone has been reported and attributed to the heat generation resulting from the friction of the drill with the dense cortical bone [26].

Various studies had shown that thermal damage at the drilling site inhibits the regenerative response in bone healing, there by slowing the process of osseointegration which result in implant mobility [13, 36, 45–47]. Bone is more susceptible to thermal injury and temperatures in excess of 47 °C can result in osseous necrosis [12]. There is a higher implant failure rate in the most dense bone types [48]. Rhinelander [41] in their study found that in the first 4 postoperative weeks, there was significantly more and earlier new bone formation and apposition on the implant surface in the metaphyseal spongy bone than in diaphyseal compact bone. This suggests better regeneration ability of spongy bone.

Various cell alterations after surgical trauma in bone tissue were reported in the literature [49, 50]. In the early stages of healing, a dental implant is associated with a necrotic zone resulting from bone drilling. With the presence of this zone, dental implants will not osseointegrate until full replacement with vital healthy bone occurs. The first step in the bone repair process largely depends on the cellular and vascular elements of the tissue [16]. Osteocytes are multifunctional cells that actively participate in cell turnover, and they are very sensitive in regard to translating aggravations to the tissues into biochemical signals. Osteocyte has been emphasized as a multifunctional cell in the dynamics of protein signaling after mechanical stimulus [51, 52]. These cells are capable of regulating bone resorption and neoformation while they are vital and even after they are dead [53]. The bone matrix proteins present an essential function as signal transduction molecules that promote cell migration [50]. An increase in the expression of these proteins occurs after tissue injury [52]. de Souza Carvalho [23] studied the influence of repeated drillings on immediate cell viability and analyzed it through the expression of bone matrix proteins. It was found that there is synthesis and release of proteins to the cell cytoplasm 2–3 min after tissue injury. Extracellular matrix proteins play an important role in the ossification process. They contribute to increasing cell activity around implants and consequent osseointegration [54, 55]. ***Osteoprotegerin (OPG), a protein which is secreted mainly by osteoblasts, is considered a physiologic regulator of bone resorption, acting directly on tissue remodeling

[56–58]. Another protein that participates in bone tissue dynamics is the activator receptor ligand of nuclear factor κB (RANKL) [59, 60]. Osteocalcin, the most abundant non collagenous protein in bone, is produced by osteoblasts and plays an important role in the tissue mineralization process. It has been suggested that its action occurs during the initial stages of bone repair, and it is essential to the regulation of osteoblast activity [61–63].

Effect of External Versus Internal Irrigation

Copious irrigation is a major factor in preventing high temperatures at the bone interface [8, 14, 19, 20]. Watanabe et al. [8] studied the heat generated that spread in the presence or absence of irrigation when drilling with IMZ, Brånemark, and ITI implant (F type) drills, They found that maximum heat generated without irrigation was higher than that with irrigation for any IMZ drill, and with irrigation, almost no heat was generated. Sener et al. [30] in their in vitro study showed that more heat was generated in the superficial part of the drilled cavity than at the bottom. Therefore, external irrigation at room temperature can provide sufficient cooling during drilling. Lower temperature saline was more effective in cooling the bone, and irrigation of the site should be continued between the drilling steps. Benington et al. [31] did a study on bovine model, to compare the temperatures that were generated with external and internal irrigation systems during bone preparation for dental implants. Statistically, no significance was observed for one irrigant delivery system over the other. The clinical benefit of using more expensive internal irrigation systems is therefore deemed unjustifiable, on the grounds that these systems do not appear to reduce the thermal challenge to the bone over and above that of simple flood irrigation. The beneficial role of external drill cooling is now generally accepted and well documented in the dental implant literature [43, 64].

Internally cooled drills and reamers were introduced to implant dentistry in 1975 by Kirschner and Meyer [65]. Because the coolant is discharged from the tip of the drill, with a hypothesis that cooling and rinsing effect of these drills would be better than with externally cooled drills [17, 66–68]. Kirchner and Meyer [65] compared internal irrigation with no irrigation at rotational speeds of 1,300 and 2,000 rpm, they reported that although there was no difference in heat generation between different rotational speeds, a bone temperature of 25–35 °C with internal irrigation reached 103 °C without it, pointing out the importance of internal irrigation. Lavelle and Wedgwood [17] measured the temperature when using round and semi-elliptical burs with internal irrigation, external irrigation, or without irrigation. They reported that high heat developed in all cases without irrigation and that minimal heat developed with internal irrigation.

Number of Blades, Drill Design and Drill Fatigue

A unique relationship was observed for burs or drills, between their cutting time and temperature at the cutting site. When cutting the cortical bone, it took time to cut with the spiral drill with its two spiral blades and a large amount of heat was generated from the tip of the blade during the drilling. The round bur, which has eight blades complete the drilling in a short time [8]. The advantage of having an extra flute in the drill design may enhance the cutting efficiency [29]. In a study, the temperature increase recorded with the 3.3 mm triflute drill was significantly smaller than that obtained with the 2 mm twist drill, despite the fact that the implant sites were not already cut by any preceding smaller diameter burs. The smaller temperature increase generated by the triflute drills may be attributed to their shape-enabling effective elimination of cutting debris while reducing frictional resistance [21]. More flutes in the design may narrow the channels of the flutes that function as a path for bone chip removal and effective elimination of the bone chips are hampered, eventually resulting in impaired cutting efficiency and elevated frictional heat. Thus more research is needed concerning the optimal number of flutes and its effect on stability, cutting efficiency and frictional heat [29].

The “relief angle” is defined as that surface adjacent to the cutting edge and below it when the tool is in a horizontal position as for turning. The “clearance angle” is defined as that surface that follows behind the edge as the bur rotates. Larger relief angles generally tend to produce a better finish on machined surface because less surface of the worn flank of the tool rubs against the workpiece [69]. Jun Oh [29], evaluated the effect of drill–bone contact area on bone temperature during osteotomy preparation. They suggest that reduction in contact area between the drill and bone reduces heat induction.

In a study by Chacon [22] three implant drill systems—system A (triple twist drills with a relief angle), system B (triple twist drills without a relief angle), and system C (double twist drills with a relief angle)—were evaluated and heat was measured. System B lacks a relief angle in its drill design and the clearance angle is the smallest of the three systems. It also has the smallest edge angle, possibly indicating a higher potential for wear, which would translate into increased heat production after multiple uses. System B has only three cutting drills in its sequence; system A has four drills and system C has five drills. A decrease in the number of drills in the drilling sequence results in larger volume of bone excavated at each step, possibly contributing to increased heat. It has been recommended that a graded series of drill sizes be used rather than one large drill [15]. As substantial amounts of bone has already been removed in the preceding sequences with smaller diameter drills, the larger diameter drills are subject to cut less bone thus resulting in smaller temperature increases [29]. If the clinician changes the drills and begins drilling in the osteotomy before allowing the temperature returning to baseline, the 40 °C increases for each drill may indeed gradually rise to a clinical concern. The use of 2–5 additional re-entries into the osteotomy by the sequential drilling may further elevate bone temperatures. So the clinicians should interrupt the drilling procedure at least every 5 s for at least 10 s, and apply saline to the bone. This interruption will dramatically decrease the time the bone temperature is elevated [24].

Among the different factors that could influence bone heating, the shape of the drill could influence bone heating during implant osteotomies [14, 21, 22]. Heat generation can be reduced by using sharp drills at slow rotational speeds [1, 70]. Drill designs are classified as disposable when intended to serve in a single surgery, while drills classified as reusable are generally designed to serve for at least ten surgical procedures. Reusable dental implant drills are widely used in clinical practice to perform osteotomy for dental implant placement [71]. Matthews and Hirsch [19] report that drill sharpness, irrigation, and the use of pilot drills will decrease temperature rise in the bone and speculate that the final osteotomy drill should perform a maximum of 40 osteotomies. Harris and Kohles [28] stated that repeated autoclave sterilization cycles cause a reduction in the cutting power of drills. However, Jochum and Reichart [72] found no statistically significant difference in bone heating between drills that were reused after washing and sterilization and drills that were used after washing only. Scarano et al. [73] published a study that evaluated the effect of re-using implant drills on alterations in temperature during osteotomy; they concluded that the increase in re-use of drills caused an increase in bone heating. With regard to repeated usage, ***scanning electron microscopy (SEM) has revealed that as few as 12 drilling procedures can degrade the cutting surface of trephine bur drills [74]. It has also been suggested that blunting of the drill edge can occur with disinfectant use and autoclaving [72].

Drill Speed

Thompson [70] investigated the mechanical effects, thermal changes, and initial histologic responses to drilling in bone at the various speeds in range of 125 to 2,000 rpm. Without the use of coolant, he observed that within this range, temperature increased from 38.3 °C to 65.5 °C with increasing drill speed. This finding was confirmed by Pallan [75]. Matthews and Hirsch [19] found a directly proportional relationship between drilling speed and heat production when comparing speed ranges from 345 rpm to 2,900 rpm. Lavelle and Wedgwood [17] reported increasing heat production with increasing rotational speeds up to 350 rpm. Eriksson et al. [76] recommended a drill speeds in the range of 1,000–2,000 rpm. Eriksson did not experimentally investigate temperature at water-cooled drilling speeds greater than 2,000 rpm. Iyer et al. [35] in their study found an inverse relationship between drill speed and heat production when coolant was used during osteotomy.

Force Applied During Osteotomy

Drill speed was not the critical determinant of heat production rather; it was change in the drilling force that was related to both the maximum temperature elevation and periods of temperature elevation [19]. Increasing the rate of advancement of the drill by increasing the drilling force does not increase heat production. Increasing both the speed and the load allows the drill to cut more efficiently than at slower speeds, thus generating less frictional heat. A similar pattern was observed in the study by Brisman [26] were they compared the drilling at 1,200 and 2,400 rpm under loads of 1.2 and 2.4 kg. Less heat was generated with 2,400 rpm under 2.4 kg of force. Hobkirk and Rusiniak [77] demonstrated that the average force placed on the hand piece during osseous preparation is 1.2 kg, but they did not investigate its influence on the generation of heat. Cordioli and Majzoub [21] found that a drilling force of 2 kg falls in the range of values used under clinical condition.

Discussion

When preparing and placing implants into bone tissue, a non traumatic surgical technique is critical. The heat generated during the preparation of the implant site is a major factor influencing implant failure [1]. Earlier studies [12, 13, 16, 17, 45] delineated the critical bone temperature beyond which bone necrosis may occur. Eriksson and Albrektsson [12] mentioned that, while placing threaded titanium implants in the rabbit tibia, found that heating the implants to a temperature of 50 °C for 1 min was sufficient to cause 30 % of the bone to be resorbed. This was not an immediate occurrence but a slow-developing process that extended over a period of 4 weeks. The bone was replaced with fat cells, preventing implant incorporation. It has been demonstrated that if bone was heated to a temperature of 47 °C for 1 min, bone necrosis, which may impede the osseointegration of an implant, can occur. However, the range of the safe drill speeds that a clinician could use was not clearly identified.

Sharawy et al. [24] in their study told about the safe drill speed and concluded that preparing an implant site at 2,500 rpm could decrease the risk of osseous damage, which may affect the initial healing of dental implants. This may decrease the devital zone adjacent to an implant after surgery and be most advantageous in immediate load application to dental implants. Slower rotational speeds required more drilling time, which produced more frictional heat. Contrary to this study, Reingewirtz et al. [78] found a positive correlation between the temperature rise and the rotation speed. A speed of 600 rpm reduced the heat production during bone cutting and the reduced drill speeds in dense bone, to reduce heat generated. Study by Reingewirtz et al. [78] and Eriksson and Adell [79] were based on one thermocouple whereas by Sharawy was based on four thermocouples to monitor the temperature rise and overall thermal profile could be detected from different regions surrounding the site of drilling. Further investigation is needed to evaluate the performance of other dental implants in humans using the drill speed mentioned by Sharawy et al. Tehemar [16] in their study stated that until proven otherwise, low hand pressure that usually falls in the range of 2 kg should be applied throughout the complete bony housing preparation to generate less heat. Abouzgia and colleagues [80–82] suggested that drilling at a high speed and with a larger load was much more desirable than using low speed and a lesser load. Manufacturers of some systems evaluated suggest drilling speeds between 1,650 (Steri-Oss, Paragon) and 2,000 (Branemark) rpm which generates less heat. Published clinical trials by Bio Horizons Dental Implants have used a drill speed of 2,500 rpm during a 3-year period and have reported survival above 99 % implant integration in all bone densities. [24] From the above discussion it was found that a drill speed of 2,500 rpm with a force of 2–2.4 kg seems to be good enough for osteotomy preparation in very less time, with less heat production and also required less time for bone to attain normal base line temperature. Further studies should be conducted to determine the ideal ratio of force and speed in vivo.

Internal and/or external irrigation with copious amounts of saline has been shown to be an effective form of coolant [12]. External cooling generally proved superior in superficial drill hole levels in compact bone and spongy bone but in deeper drill hole levels in case of cortical bone internal cooling was better.

External cooling seems beneficial along with internal cooling, particularly in compact bone as this type of bone is exceptionally sensitive to heat. For clinical use, a cooling system which combines internal and external cooling represents an expedient solution for all bone-drilling and reaming systems [25].

de Souza Carvalho [23] evaluate the influence of reusing high-resistance drills on bone heating, immediate bone cell viability, and drill wear after performing implant osteotomies. They found that there was significant bone heating after being reused 50 times and worn drills that are reused may be expected to cause excessive damage to the bone tissue and could adversely affect the osseointegration process. Allsobrook [27] investigates the effects of multiple usages of dental implant drills on bone temperature changes and to examine the cutting surfaces of these drills under a SEM. They found that drills used for up to 50 osteotomies do not appear to elevate bone temperatures to a harmful level. SEM analysis showed degradation of the cutting surfaces of the burs although the plastic deformation and surface wear did not appear to affect the cutting temperatures. Surface corrosion was observed on the cutting surfaces. Manufacturers offer only loose guidelines as to the longevity of implant drills, and it is left to the clinician to determine the life span of the drills by subjectively evaluating the efficiency of the drill through a perceived increase in the force required to perform an osteotomy [71].

The Medical Data International report on the United States dental implant market indicates that the average implant-based restoration procedure involves the placement of 2.5 dental implants, meaning that a reusable drill should retain its cutting surface for the preparation of at least 25 implant cavities [71]. Clearly, a shortage of scientific data on the actual longevity of surgical drills still exists, and without this knowledge it remains difficult for a surgeon to assess the proper time to replace a used drill with a new, unused one [28].

Measures to Reduce Heat Generation by Dental Implant Drills During Osteotomy

- When preparing and placing implants into bone tissue, a non traumatic surgical technique is critical.
- Bone is more susceptible to thermal injury and temperatures in excess of 47 °C can result in osseous necrosis. Avoid excessive temperature generation during surgical drilling.
- For clinical use, a cooling system which combines internal and external cooling represents an expedient solution for all bone-drilling and reaming systems.
- Clinicians should interrupt the drilling procedure at least every 5 s for at least 10 s, and apply saline to the bone. This interruption will dramatically decrease the time the bone temperature is elevated.
- It has been recommended that a graded series of drill sizes be used rather than one large drill.
- Reduction in contact area between the drill and bone reduces heat induction.

- More flutes in the design may narrow the channels of the flutes that function as a path for bone chip removal and effective elimination of the bone chips are hampered, eventually resulting in impaired cutting efficiency and elevated frictional heat.
- It is left to the clinician to determine the life span of the drills by subjectively evaluating the efficiency of the drill through a perceived increase in the force required to perform an osteotomy.
- A drill speed of 2,500 rpm with a force of 2–2.4 kg seems to be good enough for osteotomy preparation in very less time, with less heat production and also required less time for bone to attain normal base line temperature.

Conclusions

Many articles conclude that excessive heat generated by the drills will induce bone necrosis. Even the force applied on the hand piece will enhance the heat in the bone. A drill speed of 2,500 rpm with a force of 2–2.4 kg seems to be good enough for osteotomy preparation in very less time, with less heat production and also required less time for bone to attain normal base line temperature. Further studies should be conducted to determine the ideal ratio of force and speed in vivo, exact characteristics of drill design that may actually degrade with repeated use. Studies to optimize drill/bone contact dimensions are needed. Establishment of link between relief/clearance angles and increased temperatures should be evaluated.

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