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Thermal Analysis of Dental Drilling: A Review

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Abstract— Dental drilling is a common practice for dental surgeons. Heat generated during dental drilling causes elevation in temperature of bone being drilled. Heat generation is affected by different factors like: drill diameter, drill speed, drill feed etc. A lot of studies have been carried out to investigate the effect of each factor on heat generation during drilling of human bone. In this work previous works on dental drilling are reviewed by comparing parameters, experimental set up, material and conclusions of various studies. On the basis of previous studies conclusion and future scope for work has been derived.
Keywords— Dental drilling, Bone, Temperature, Drill diameter, Drill speed.

I. INTRODUCTION

Drilling is primarily done to create a site for the placement of artificial tooth known as dental implant. Dental drilling plays an important role in the process as bone healing is considerably affected by the amount of the rise in temperature during drilling. Heat is generated during dental drilling due to the friction between dental drill and bone. Some amount of heat generated during drilling at the tip of the drill is transferred to the bone which results in heating of bone. The heat transfer to the bone by dental drill is a complex system and is dependent on: drill and drilling parameter, ambient temperature. Different studies have been carried out using a set of parameters. These studies involved direct or indirect temperature measurements of bone during drilling of bone or artificial material like PMMA (Ploy methyl meth acrylayte). PMMA has similar thermal properties compared to human bone[1].The threshold temperature beyond which bone cells are damaged has been found out to be 47˚C [2]. There are number of articles concerning drilling but some contradictions are still present [3]. This study involves review of previous work done on heat generation during dental drilling.

II. DENTAL DRILLING PARAMETERS

Dental drill and drilling parameter selection is a critical decision as each parameter has its own effect on heat generation. These factors will be discussed one by one and conclusions of various studies will be compared.

A. Drill Design

Drill design plays an important role as heat is generated by cutting action of drills cutting face and removal of chip is also to be facilitated through the drill. An improper drill design may lead to excessive heat generation and damage bone. Factors involved in drill deign are listed below:

1) *Drill Flutes*
2) *Drill Point Angle.*
3) *Drill Point Design*

Reference [4] studied heat production by three implant drill systems : system A(double twist drill with relief angle), system B (triple twist drill without relief angle) and system C (double twist drill with a relief angle). They concluded drill geometry plays a major role in heat production and may explain the increased temperature readings seen in system B. System B drills lack relief angle and have the smallest clearance angle of the 3 systems hence more heat generation. A study found that the 3- fluted drill significantly outperforms the 2 fluted drill not only in target ability but also in the range of permissible approach angles[5]. A study using drill point angle of 80˚, 100˚ and 120˚ did not show significant difference on increase in bone temperature during drilling for 2.7, 3.2 and 4.5 mm drills [6].

B. Drill Diameter

Drill diameter is an important factor in heat generation during dental drilling. A study was carried out on 3 different drill diameter 2, 3.5 and 4.3 mm and their effect on heat generation [1]. The study concluded that the drill diameter increases and leads to more heat generation. Another study also recorded an increase in drill diameter leads to increase in heat generation [6]. Reference [7] investigated the optimal combination of drill diameter, feed rate and drill speed in dry drilling of PMMA by Taguchi method. They also concluded drill diameter has the highest influence on temperature produced during drilling PMMA.

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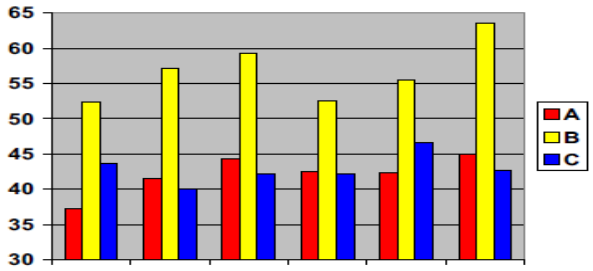

Fig1 : Adjusted mean temperature by system and number of uses[4].

C. Drill Material

Drill material is related to thermal conductivity of material so affects the heat generation. Reference [8] studied the influence of drill material on development of intrabony temperature. The following drill materials were tested: steel (external and internal cooling); steel coated with zirconium nitride and zirconium oxide. There was no significant difference in heat generation between the drill materials. A study compared the heat generated during dental drilling by using stainless steel and ceramic drills[9]. They concluded that heat modification seemed not to be related with drill type, in the deep aspect of the cavity.

D. Drill Wear

Drill wear occurs when a single drill is used repetitively. A study evaluated three implant systems after 25 uses[4]. Fig1 shows two drill systems (A and C) had acceptable temperature measurements out of 25 uses. System B (triple twist drill without a relief angle) showed significantly higher heat production with little signs of visual wear as compared to the other 2 systems. . Reference [10] tested three drills (Leibinger 1.5 mm diameter twist drill): new drill, another after 600 holes drilled and third after usage in theatre after several months. There was a significant difference in temperature rise which was proportional to amount of wear. Another study assessed thermal changes and drill wear in bovine bone during implant site preparation by using twisted stainless steel and ceramic drills [11]. It was observed that the stainless steel produced higher temperature when compared to ceramic drill. Regarding drill wear they found no severe signs of drill wear on either drill after 50 uses.

E. Drill speed(r.p.m.)

Drill speed is one of the drilling parameter which is controlled by surgeon during dental drilling. A lot of studies have been carried out to find out relationship between drill speed and heat generation. Reference [12]studied the effect of three different drill speeds (1225, 1667 and 2500 rpm) using 4 implant systems. They founded out of the three different drill speeds, preparing implant site at 2500 rpm could decrease the risk of osseous damage. Another study evaluated effect of 100, 500 and 1000 rpm on early bone healing in oral implants[13]. They found out that drill speed is one of the decisive factors for early osseointegration and drilling at 1000 rpm seemed to yield the strongest biologic responses. Reference [14] studied effect of high speed drilling on bone temperature tests were conducted at variable speeds (20000- 100000 rpm) and at different forces (1.5 – 9 N).The results revealed that temperature elevation decreased with increasing speed and force. Reference [15] studied temperature change in pig rib bone by low speed drilling. They concluded that drilling at 50 rpm without irrigation did not produce overheating. Another study compared effect on heat generation by low speed drilling (50 rpm) without irrigation and conventional drilling (800rpm) under irrigation [16]. No histological differences between the two drilling speeds were found. Reference [1] studied three different speeds of 1200, 1800 and 2200 rpm with constant feed rate of 0.0508 m/s. An increase in temperature with increasing drill speed was recorded but keeping the feed constant.

F. Drill Feed

Drill feed is generally controlled by application of force on hand piece by the dental surgeon. Increase force or feed rate means reduction in overall drilling time. A study performed experiment at different feed rates of 0.0508 m/s, 0.1016 m/s and 0.1524 m/s[1]. It was observed that feed rate of 0.1524 m/s produced lower temperature as compared to the lower feed rates. Reference[14] tested for a combination of different speeds and applied weight to measure heat produced. It was observed that drilling at high speed with large load decreases the temperature rise and reduces overall drilling time.

G. Irrigation

Irrigation facilitates the removal of heat from drill site by application of fluid or pressurized air. There are two types of irrigation:

1) *External Irrigation*

2) *Internal Irrigation*

The main difference between two is that in internal type the fluid is circulated within the drill and in external fluid is pumped from outside on to the site of drilling. Studies have been carried out to compare two types of irrigation. A study observed a significant temperature rise without a coolant [1]. The study compared external irrigation with no irrigation and concluded that temperature rises considerably without coolant. Reference [8] compared external and internal irrigation. They found that steel drills with internal cooling generated significantly less heat than drills with external cooling. Another study found no significant difference in the generation of heat between internal and external cooling [18]. He concluded additional external cooling seems beneficial for any internal cooling. Reference [19] compared external irrigation and double irrigation (both external and internal). They found out that double irrigation technique produced a significantly smaller increase in temperature.

H. Drilling Technique (Continuous or Incremental)

There are two techniques used to create a desired hole on a dental site. Continuous drilling involves use of single drill of final hole and incremental (graduated) drilling involves gradually increasing drill diameter to get desired drilled diameter. Reference [1] compared single step drilling with graduated drilling. Experiments were performed drilling 3.5 mm and 4.3 mm holes by single step and graduated drilling. Fig 3 shows maximum temperature obtained by drilling a 3.5 mm diameter drill is 55˚C whereas maximum temperature obtained by gradually increasing the diameter from 2mm to 3.5 mm is 45˚C. Reference [20] studied effect of simplifying dental sequence on osseointegration. Implants were placed in tibia of beagle dogs by simplified technique(Pilot drill + final diameter drill) and conventional drilling sequence. The results of this study suggested that osteotomy preparation may be simplified and less consuming; however, constant irrigation will always be necessary to avoid the harmful effects of temperature elevation in bone.

I. Other Factors

Other factors which effect heat generation are type of bone (diaphysis or metaphysis), age and sex of patient. Reference [21] studied IMZ implant fixation on the diaphysis (compact bone) and metaphysis (compact bone) of left distal tibia in each of six sheep. They found out that spongy bone apparently tolerates drilling heat better and reacts with more and earlier new bone formation. A study observed statistically significant difference in temperature was found at the depths of 3, 6, and 9 mm between using surgical drill guides and classical drilling procedure [22]. From a heat generation standpoint, they concluded that preparing an implant site with using surgical drill guides generates heat more than classical implant site preparation regardless of the irrigation.

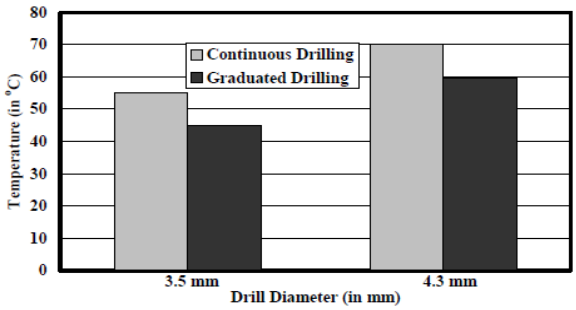

Fig. 3 Temperatures when drilled continuously & gradually for 3.5 and 4.3 mm holes [1]

Fig 4 Degusa F1 Milling machine modified [4]

III. EXPERIMENTAL SET UP

To study the effect of temperature elevation on bone the experiments are carried out by making a drilling set up and drilling is carried out on animal bone or artificial material like PMMA. We have compared different studies in terms of drill system used, method used for temperature measurement, material used and range of parameters.

TABLE I
COMPARISON OF EXPERIMENTAL SET UP AND PARAMETERS

Author	Drill System	Material	Temperature Measurement	Range of Parameters
M.B. Abouzgia et.al [14]	Surgical drill(Stryker 100) Specially constructed drill press, Load cell	Human Femur bone	K type thermocouple connected to a data acquisition system	Drill speed (rpm): 20000 to100000 Load (N): 1.5 to 9.0 Drill Diameter (mm): 2.5
M . Sharway .et. al [12]	Two internally irrigated drill systems and two externally irrigated	Pig bone	K type thermocouple	Drill speed (rpm): 1225,1667,2500 Drill Diameter (mm): 1.5 to 4 (17 nos.) Drilling depth(mm): 13
Kalidindi [1]	Drilling machine (HAAS VFOE 20 HP)	PMMA	K type thermocouple IO tech Daqbook/260, 14 Channels, Thermocouple placement : 6 and 12 mm	Drill speed(rpm): 1200,1800,2200 Drilling depth(mm): 8,12,6 Drill Diameter (mm): 2,3.5, 4.3 Drill feed rate (m/s): 0.00508,0.01016,0.01524
Chacon et. al [4]	Degusa F1 milling Machine modified KaVo intra 3624 handpiece with oral max drill system	Bovine femoral cortical bone	K type thermocouple	Drill speed (rpm): 2500 Load (kg): 2.4 Drill Diameter (mm): 4.0 , 4.2 Three implant drill systems External irrigation(ml/min): 40
M. Sumer et. Al [9]	A Bego Paraskop M milling machine modified to accept a WH 985 AE handpiece	Bovine femoral cortical bone	Four-Channel, Handheld Data Logger Thermometer	Drill speed (rpm): 1500 Load (kg): 2.0 Drilling depth(mm): 3,6,9
R.K Pandey. et. al [7]	3 axis MTAB flexmill	PMMA	K type thermocouple NI DAQ 9219 Data acquisition system	Drill speed(rpm): 1500,2000,2500 Drill Diameter (mm): 2,3.5, 4.3 Drill feed rate (mm/min): 35,40 ,45
S. Harder et. al [8]	Handpiece KaVo intra 3624 driven by motor (Intrasurg 1000,Kavo) mounted in lifting machine	Bovine Ribs	Type T Cu- Ni thermocouples	Drill speed (rpm): 1200 Drill Diameter (mm): 2 , 3 Drilling depth(mm): 13

IV. CONCLUSIONS

It was observed that different studies have been carried out to find optimum drilling speed for minimum heat generation but each experiment has different set of parameters so the parameters cannot be generalized. An increase in drill diameter leads to more heat generation during dental drilling. An increase in drill speed or drill feed leads to less heat generation as the overall drilling time is reduced by increment in any of the factor. But excessive increase in drill feed or speed may adversely affect the dental drilling as it may cause drill failure, inaccurate hole or permanently damaging the bone around the drilled hole. Older drills produce more heat as compared to the new drills because of drill wear caused due to repetitive use of drills. Irrigation plays an important role in dissipation of heat. Use of external or internal irrigation reduces the risk of thermal damage to bone. PMMA has similar properties to bone and can be used as replacement of bone during experiments. Incremental drilling generates less heat when compared to continuous type dental drilling. The sequence of incremental drilling can further be

investigated in terms of reduction in overall drilling time while avoiding any thermal damage to the bone. Effect of Use of drill guide during dental drilling can be studied in detail. Study of Heat distribution during drilling is a very complex due to anisotropic nature of bone. Further studies can be carried out for detailed distribution of heat during dental drilling.

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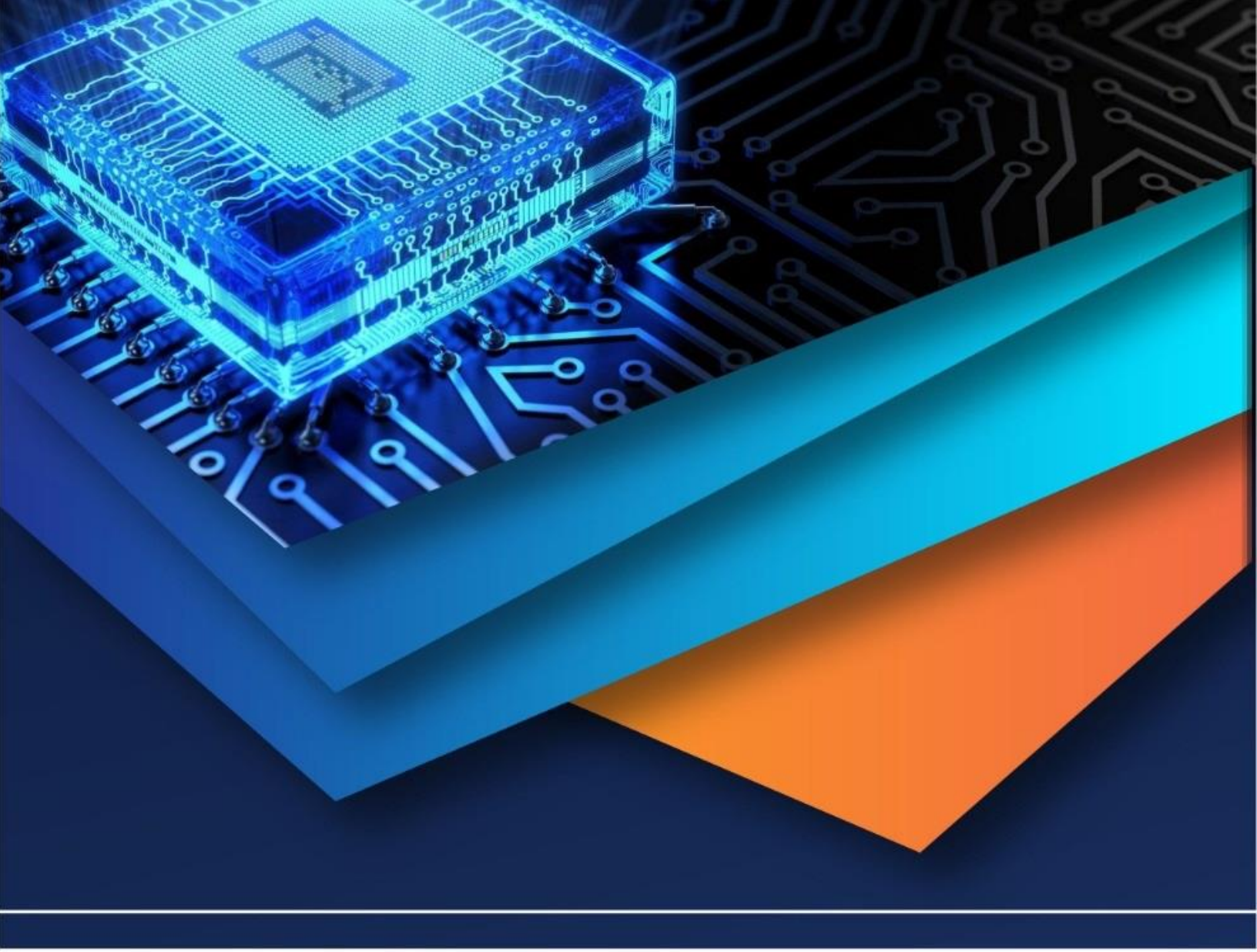

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