Various Bio-mechanical Factors Affecting Heat Generation during Osteotomy Preparation: A Systematic Review

Abstract

Background: As implant site preparation and bone are critical precursors to primary healing, thermal and mechanical damage to the bone must be minimized during the preparation of the implant site. Moreover, excessively traumatic surgery can adversely affect the maturation of bone tissue at the bone/implant interface and consequently diminish the predictability of osseointegration. So, this study was carried out to evaluate the various biological and mechanical factors responsible for heat generation during osteotomy site preparation to reduce the same for successful osseointegration of dental implants. Study Design: A broad search of the dental literature in PubMed added by manual search was performed for articles published between 1992 and December 2015. Various bio-mechanical factors related to dental implant osteotomy preparation such as dental implant drill designs/material/wear, drilling methods, type of irrigation, and bone quality were reviewed. Titles and abstracts were screened and articles which fulfilled the inclusion criteria were selected for a full-text reading. Results: The initial database search yielded 123 titles, of which 59 titles were discarded after reading the titles and abstracts, 30 articles were again excluded based on inclusion and exclusion criteria, and finally 34 articles were selected for data extraction. Many biological and mechanical factors responsible for heat generation were found. Conclusion: Literatures of this review study have indicated that there are various bio-mechanical reasons, which affect the temperature rise during osteotomy and suggest that the amount of heat generation is a multifactorial in nature and it should be minimized for better primary healing of the implant site.

Keywords: Bone quality, dental implant drills, dental implant osteotomy, drilling methods, heat generation, type of irrigation

Introduction

Dental implant is one of the effective treatment modalities for the replacement of missing tooth. The success of the implant depends on how strongly a bone can heal around the implant, a process known as “Osseointegration.” For successful implant therapy, the salvation of the vitality of the differentiated and undifferentiated cells of bone, which participate in osseointegration cascade and provide anchorage of endosseous implants to tolerate the functional load, is an important prerequisite.[1‑2] This osseointegration process is dependent on several factors, but the most important is the essential primary healing around the dental implant.[3] Thermal damage at the drilling site inhibits bone regeneration leading to hyperemia, fibrosis, osteocyte degeneration, increased osteoclastic activity, and necrosis, consequently being a major factor, influencing implant survival.[4‑7] There are numerous bio-mechanical factors, which contribute to the heat generation during drilling. Various strategies have been employed to reduce heat generation during implant site preparation, including variations in drill designs, methods of drilling, and coolant delivery. However, there is a lack of unanimity regarding the factors affecting heat generation and there is relatively little in the implant literature on these topics.

Materials and methods

Search strategy

A broad search of the dental literature in PubMed added by manual search was performed for articles published between 1992 and December 2015. The key words searched were; Heat generation, Dental implant drills, Drilling methods, Type of irrigation, Bone quality, and Dental implant osteotomy. Manual searches of...
the references of all full-text articles and relevant articles, selected from the electronic search, were also performed.

**Inclusion criteria**
- Implant site
  - Compact bone
  - Cancellous bone.
- Drill’s characteristics
  - Drill design
  - Drill material/coating
  - Drill wear.
- Drilling methods
  - Single/sequential drilling
  - Continuous/intermittent drilling
  - High speed/low speed
  - Drill force/drill load
  - Use of surgical guide.
- Mode of irrigation
  - Single/double irrigation
  - Internal/external irrigation.
- Study design
  - Controlled experimental *in vitro* trials
  - Randomized controlled trials.

**Exclusion criteria**
- Incomplete data
- Review articles
- Study articles related other than dental field
- Studies not meeting any of inclusion criteria
- History of any major–minor dental surgeries
- Any case report studies/case series
- *In vivo* animal studies.

**Result of search**
The database search yielded 123 titles, of which 59 titles were discarded after reading the titles and abstracts, 30 articles were again excluded based on inclusion and exclusion criteria, and thus finally 34 articles were selected for data extraction [Figure 1].

**Data extraction**
Data of the finally included studies were tabulated and the following information were extracted: implant site, implant system, drill’s characteristics, drilling methods, type of irrigation, temperature assessment, and the results of included research studies. No statistical analysis was done as this is a qualitative review study. Table 1 summarizes data.[8-40]

**Discussion**
Dental implant surgery process involves osteotomy preparation inside the bone, which causes heat generation due to the friction between the drill and bone. Overheating is constantly mentioned as a risk factor for bone necrosis that could compromise the dental implant primary stability. The negative effect of heat on bone results in the denaturation of the membrane and enzymatic proteins, decreased osteoclastic and osteoblastic activity, hyperemia, necrosis, fibrosis, dehydration, and desiccation, which may all contribute to cell death.[41-45] This review study mainly concentrates on the factors, reducing the amount of temperature rise during the dental implant surgery for better osseointegration process.

**Bone density**
An atraumatic surgical technique for dental implant is critical. Heat generation during osteotomy preparation varies according to the bone quality. Bone usually varies in density from person to person, bone to bone in the skeleton, and from site to site in the same bone. Regarding the effect of density on the temperature generated, Yacker and Klein reported that bone density is a far greater indicator of bur temperature than depth of the osteotomy.[9] The architecture and vascularization of the bone play an important role in the reaction of bony tissue to the effect of heat. As the spongy bone is well supplied with blood vessels, it can dissipate the heat faster and thus has a greater capacity for regeneration than compact bone, which has a poor blood supply. Cortical bone is dense and contains little water, so its thermo-conductive capacity is higher than in the bone marrow, with relatively rapid conduction of heat, while spongy bone has a lattice structure and contains water and lipids. So, the generation of frictional heat in the cylinder wall of spongy bone is unlikely to spread at periphery.[8] Results of various studies shown that, irrespective of drill type, more heat was generated in the superficial part of the bone (compact bone) rather than osteotomy preparation in deep part of bone (cancellous bone).[25] As the duration of drilling is longer for the compact bone compared with the spongy bone, the temperature increase was higher in the cortical (superficial) bone. This may explain why there is some bone resorption at the implant neck area immediately after placement when heating is not carefully controlled.[20]
Table: 1 Summarized data [reference from]

| Serial number | Author | Bone type | Drill’s descriptions in detail | Drilling methods | Type of irrigation | Conclusion |
|---------------|--------|-----------|---------------------------------|------------------|-------------------|------------|
| 1             | Watanabe et al., 1992[^8] | Pig rib | The 4.0 mm diameter burs for the IMZ implant system. The five high-speed drills (guide drill, spiral drill, pilot drill, twist drill, and countersink drill) for the Brånemark implant, and spiral drill and trephine bur for the ITI implant system | 500 g of drilling load | With and without irrigation | 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 for any IMZ, ITI, and Brånemark drill |
| 2             | Yacker and Klein, 1996[^9] | Block of bovine bone | 2-mm diameter bur | Sequential drilling with depths of 8.5, 10.5, 13.5, 15.5, 18.5, and 20.5 mm | With and without irrigation | During osteotomy, preparation without irrigation, bur temperatures far in excess of 47°C were reached in a matter of seconds routinely. Precise irrigation greatly aids in lowering bur temperature. Bone density is a far greater indicator of bur temperature than is the depth of the osteotomy |
| 3             | Brisman, 1996[^10] | Bovine femoral cortical bone | Three burs of increasing widths 2.00 mm pilot, 2.50 mm spade, and 3.25-mm spade | Drilling speeds of 1800 and 2400 rpm and drilling loads of 1.2 and 2.4 kg, respectively | External irrigation | Independently increasing either the speed or the load caused an increase in temperature in bone. However, increasing both the speed and the load together allowed for more efficient cutting with no significant increase in temperature |
| 4             | Benington et al., 1996[^11] | Bovine mandibles | Three drills round drill - 2-mm spiral twist drill - 3-mm pilot drill | Sequential drilling using Brånemark technique | No irrigation | Temperature changes occur at and around the implant site with the sequential drilling |
| 5             | Abouzgia and Symington, 1996[^12] | Bovine cortical bone | - | Drill speeds range from 20,000-100,000 rpm At different constant force (1.5-9 N) | - | Temperature rise and the duration of temperature elevation decreased with speed and force, suggesting that drilling at high speed and with large load is much more desirable than previously thought |
| 6             | Cordioli and Majzoub, 1997[^13] | Bovine cortical femur bone | 10-mm long twist drills (2- and 3-mm diameter) and triflute drills (3.3- and 4-mm diameter) | 4- and 8-mm depth drilling Speed at 1500 rpm load of 2000 g drilling with surgical guide | External irrigation | Significantly lower temperature rise was observed with triflute burs at both drilling depths The efficacy of triflute drills in reducing frictional heat did not seem to decrease with cavity depth, suggesting that the geometry of the triflute burs combines cutting efficacy with better heat dissipation capabilities than twist drills at the drilling depths |

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Table: 1 Contd...

| Serial number | Author                   | Bone type                  | Drill’s descriptions                          | Drilling methods                  | Type of irrigation                                      | Conclusion                                                                                                                                 |
|---------------|--------------------------|----------------------------|-----------------------------------------------|-----------------------------------|---------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| 7             | Abouzgia and James, 1997 | Bovine cortical bone specimens | 2.5-mm standard surgical twist drill bits (0838-13, Howmedica, France) | Drilling speed, 49,000 rpm, and at forces in the range of 1.5-9.0 N | No irrigation was applied, to avoid introducing another parameter in the experiment | It also appeared that the use of external irrigation was not crucial to control heat generation during tapping procedures for screw-shaped implants. The temperature increased with force, up to about 4.0 N, and then decreased at forces greater than that because of decreased drilling time. A separate series of tests revealed that temperatures were higher in the longitudinal direction than in the circumferential direction; this difference was attributed to the anisotropic thermal properties of bone. Temperatures measured at all times were below the bone injuring level. Drills reused more than 40 times stood out with an increased number of higher temperatures. So, cannon drills of the ZL-duraplant system® should not be reused >40 times. |
| 8             | Jochum and Reichart, 2000 | Pig’s mandibles            | Timedur cannon drills                          | Maximum rotational speed of 1200 rpm with low pressure | Water irrigation (70 ml/min room temperature)           | 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, over that of simple flood irrigation. Drill design, material, and mechanical properties significantly affect cutting efficiency and durability. Coolant availability and temperature were the predominant factors in determining bone temperatures. 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. |
| 9             | Benington et al., 2002   | Bovine model               | 2-mm twist cutting drill and the 3.25 trephining or enlarging drill | Constant drill load of 1.7 kg rotational speed of 2500 rpm | Internal and external irrigation systems                | 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, over that of simple flood irrigation. Drill design, material, and mechanical properties significantly affect cutting efficiency and durability. Coolant availability and temperature were the predominant factors in determining bone temperatures. 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. |
| 10            | Ercoli et al., 2004      | Bovine ribs                | Spade, twist, tri-flute, and TiN-coated drill designs | Intermittent cutting              | Custom-made water bath/water pump system (Haake D3; Thermo-electron, Karlsruhe, Germany) | 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, over that of simple flood irrigation. Drill design, material, and mechanical properties significantly affect cutting efficiency and durability. Coolant availability and temperature were the predominant factors in determining bone temperatures. 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. |
| Serial number | Author            | Bone type                        | Drill’s descriptions                                      | Drilling methods | Type of irrigation | Conclusion                                                                 |
|---------------|-------------------|----------------------------------|-----------------------------------------------------------|------------------|-------------------|-----------------------------------------------------------------------------|
| 11            | Chacon et al., 2006[18] | Bovine cortical bone            | System A-Triple twist drill with a relief angle System B-Triple twist drill without relief angle System C-Triple twist drill with a relief angle | Intermittent drilling Constant 2.4 kg load Drill speed: 2500 rpm Drilling depth: 15 mm | External irrigation with 40 ml/min | Drill geometry plays a major role in heat production with increased temperature in System B, this study also shows that temperature increases when drills are used multiple times |
| 12            | Misir et al., 2009[19]          | Bovine femoral cortical bone    | Drilling in test groups with surgical drill guides Drilling in control groups with classical implant site preparation | Constant drill load - 2 g drilling speed at 1500 rpm Drilling depth 3, 6, and 9 mm | System A-with external irrigation System B-with both external and internal irrigation | Preparing implant site using surgical guides generates heat more than classical implant site preparation regardless of the irrigation type |
| 13            | Sener et al., 2009[7]           | Fresh frozen edentulous segments of bovine mandibles | 16-mm long drills Sequential drilling with depths of 3, 7, and 12 mm rotation speed of 800 rpm | Drilling without irrigation, versus drilling with irrigation |                                                                                       | More heat was generated in the superficial part of the drilling 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 |
| 14            | Kim et al., 2010[20]            | Pig ribs                        | Twist drill (2.0 mm/2.5 mm) Conventional drilling versus low-speed drilling Static load of 10 kg Drilling speed 50 rpm | Without irrigation |                                                                                       | No implant drill system produced heat exceeding 47°C, which is the critical temperature for bone necrosis during low-speed drilling. Low-speed drilling without irrigation could be used during implant site preparation |
| 15            | Flanagan, 2010[21]              | Bovine mandibular ramus         | All drill sequences were initiated with 2-mm diameter drill followed by 2.3 mm, 2.8 mm, and 3.3 mm | Sequential drilling | No irrigation of any kind was used | The initial temperature of the bovine ramus was 37.7°C. During the osteotomy, the temperature rose to 52.6°C and quickly declined when the drilling ceased. In vitro osteotomy resulted in a significant temperature rise. The nonvital bone obviously was not covered with soft tissue nor has a blood supply, which may be important in heat dissipation. Cooling irrigation has been advocated to prevent osseous overheating during an implant osteotomy |

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| Serial number | Author | Bone type | Drill’s descriptions | Drilling methods | Type of irrigation | Conclusion |
|---------------|--------|-----------|---------------------|------------------|------------------|------------|
| 16 | Rashad et al., 2011 [22] | Bovine ribs | Loads of 5, 8, 15, and 20 N | - | Irrigations of 20, 50, and 80 ml/min | Ultrasonic implant site preparation is more time-consuming and generates higher bone temperatures than conventional drilling. However, with the levels of irrigation, ultrasonic implant site preparation can be an equally safe method |
| 17 | Oh et al., 2011 [23] | Artificial bone | Conventional triflute 3.6 mm drills | Continuous drilling | No irrigation | Within the limitations of this pilot study, the observations herein suggest that reduction in contact area between the drill and bone reduces heat induction |
| 18 | Scarano et al., 2011 [24] | Bovine cortical bone | Cylindrical drill (3.7 mm) with a triple twist system and a conical drill (3.7 mm) with a quadruple twist system | Speed of 800 rev/min. Intermittent drilling | Temperature-controlled saline bath (26.0°C) | The model system used in this work was able to evaluate the temperature in the cortical bone and in the apical portion of the drills; the temperature modifications in the apical portion of the drill seemed to be correlated with the drill geometry. The results of the present study showed that drill geometry seems to be an important factor in heat generation during implant site preparation |
| 19 | Sumer et al., 2011 [25] | Bovine femoral cortical bone | Two different implant drill types - stainless steel and ceramic | Drilling depths of 3, 6, and 9 mm | Constant water bath - saline irrigation | Within the limitations of the study, more heat was generated in the superficial part of drilling cavity with ceramic drill while heat modification with deep part of drilling cavity seemed not to be correlated with drill type |
| 20 | Misic et al., 2011 [26] | Pig ribs | For lateral bone condensing marker burs ø1.4 mm and ø2.3 mm, pilot drill ø2.2 mm and a series of increasing diameter bone condensers ø2.8 mm and ø3.5 mm were used. For Conventional bone drilling round burs ø1.4 mm and ø2.3 mm, pilot drills ø2.2 mm and ø2.8 mm and twist drill ø3.5 mm were used. | Lateral bone-condensing (experimental group) and bone-drilling techniques (control group) at depths of 1, 5, and 10 mm in tripod configuration | Lateral bone condensing without irrigation | The bone-condensing technique applied in the jaw bone class D4 offers an advantage over bone drilling because it generates a significantly smaller amount of heat |
| Serial number | Author                      | Bone type                       | Drill’s descriptions | Drilling methods | Type of irrigation                        | Conclusion                                                                 |
|---------------|----------------------------|---------------------------------|----------------------|------------------|-------------------------------------------|---------------------------------------------------------------------------|
| 21            | Bulloch et al., 2012[27]   | Bovine femoral bone             | Cannulated single drilling at depth of 3.5 mm and 4.2 mm at a constant speed of 2,100 rpm and pressure of 2 kg | Sequential drilling with and without using surgical guide | Continuous room temperature irrigation | Cannulated single drill technique does not cause an increase in bone temperature greater than that seen with standard sequential drilling with or without a surgical guide |
| 22            | Oliveira et al., 2012[28]  | Bovine ribs                     | Twisted stainless steel and ceramic drills, drilling depth 8 and 10 mm, drilling speed of 800 rpm | -                | Constant irrigation of 50 ml/min of saline solution at room temperature | Statistically significant higher bone temperatures were obtained with stainless steel drill (1.61°C), when comparing with the ceramic drill (1.31°C). No severe signs of wear of either drill were detected after fifty uses |
| 23            | Gabrić Pandurić et al., 2012[29] | Bone blocks from porcine ribs | 1-mm wide stainless steel pilot drill Er:YAG laser | Drilling parameters; low speed drilling at 1500 rpm Laser parameter 20-W power, 1000 m pulse energy 20-Hz frequency, 300-µs pulse duration 0.9 mm spot size, λ value equal to 2.94 µm | Constant saline irrigation | The Er:YAG laser produced preparation with regular and sharp edges, without bone fragments and debris, in a shorter time and with less generated heat |
| 24            | Marković et al., 2013[30]  | Pig ribs                        | Maximum insertion torque values of 30, 35, and 40 Ncm Drilling depths at 1, 5, and 10 mm | Surgical technique (lateral bone condensing and standard bone drilling) and implant macrodesign (self-tapping and nonself-tapping) | Thermostat-controlled water bath | Placement of self-tapping implants with low insertion torque into sites prepared by lateral bone-condensing technique might be advantageous in terms of thermal effect on bone |
| 25            | Koo et al., 2015[31]       | Bovine scapular bone            | TiN-coated metal drills, tungsten carbide carbon-coated metal drills, zirconia ceramic drills | Sequential drilling to the depth of 11 mm | Without irrigation versus irrigation | No significant difference was found between drill materials The initial drill should be changed in osteotomy preparation with irrigation after they have been used 50 times irrespective of drill material |

Contd...
| Serial number | Author(s)          | Bone type | Drill’s description | Drilling methods | Type of irrigation                                                                 | Conclusion                                                                                                                                 |
|---------------|--------------------|-----------|---------------------|------------------|----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| 26            | Harder et al., 2013 | Bovine ribs | Steel drills        | Drill speed of 1200 rpm, Force of 1 kg for pilot drills and 0.5 kg for implant drills, Drilling depths of 4, 8, and 12 mm | External irrigation versus internal irrigation                                                                                         | Irrigation may be a more critical factor for the control of temperature elevation than the drill material                                      |
| 27            | Gehrke et al., 2015 | Synthetic blocks of type 1 bone density | 4.1 mm diameter drill for cylindrical implant and 4.3 mm diameter drill for conical implant 4.2 mm diameter single drill for conical implant | Groups 1 and 2 with conventional sequential drilling method, Group 3 with single bur drilling technique | Without irrigation versus external irrigation                                                                                           | The method of cooling affected the development of the intrabony temperature during preparation of site of the implant, but the drill material seemed to play no particular role |
| 28            | Gehrke et al., 2013 | Bovine ribs | -                   | Continuous versus intermittent drilling methods at the depth of 10 mm | External irrigation versus double irrigation methods                                                                                   | The single bur drilling protocol did not produce greater bone heating than the convention protocol and may be considered a safe procedure |
| 29            | Strbac et al., 2014 | Bovine rib | Twist (2 mm) and conical (3.5/4.3/5 mm) drills | Automated intermittent drilling, Drilling depth 10-16 mm | With and without different irrigation methods (external, internal, and combined)                                                     | Combined irrigation provides sufficient reduction in temperature changes during drilling and it may be more beneficial in deeper site osteotomies |
| 30            | Strbac et al., 2014 | Novel standardized bovine specimens | Twist drills of 2 mm ø and conical drills of 3.5, 4.3, and 5 mm ø | Automated intermittent and graduated drilling sequences - drill depths of 10 versus 16 mm | Without any coolant supply with 29.87°C, followed by external with 28.47°C and then internal with 25.86°C and combined irrigation with 25.68°C | Combined irrigation provides sufficient reduction in temperature changes during drilling and it may be more beneficial in deeper site osteotomies |
| 31            | Lucchiari et al., 2014 | Bovine ribs | Drill diameter of 3.5 mm for both drilling methods | Multiple drilling method versus Single drill method | Subgroups A1 - B1 with irrigation, Subgroups A2 - B2 without irrigation                                                             | The single drilling method induced a significantly greater variation in temperature than the traditional method, but only when irrigation was used. Without irrigation, the difference in the temperature variation generated by two methods was not statistically significant |
| 32            | Gehrke et al., 2014 | Synthetic blocks of type 1 bone density | Trephine drills of 5 mm diameter | Drilling depth of 5 mm | Group 1 - No irrigation, Group 2 - External irrigation, Group 3 - Double irrigation                                                  | The double irrigation technique resulted in a smaller increase in temperature in the cortical bone model, demonstrating a greater efficiency, which may be beneficial when compared to external irrigation only |

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Drill geometry

With the great variety of dental systems commercially available, comparison between the different designs and shapes of drills seems to be impossible. Root form implants vary considerably in design for biologic and mechanical reasons. One study suggested that the geometry of triflute burs has cutting efficacy with greater heat dissipation capabilities than twist drills. Chacon had done study to measure heat generated in bone by three implant drill systems with different drill geometry. The 3-implant drill systems including 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. System A and C drills had temperature measurements below 47°C, even after 25 uses. The temperatures of system B drills exceeded 47°C from the initial use. When cutting the cortical bone, it took time to cut with the spiral drill from the tip, and a large amount of heat generation had been noticed during the drilling. The round bur having eight blades with greater cutting efficiency can complete the drilling in a short period of time. Before the cannon drill, the round bur should be used to remove cortical bone and the implant site is indented with drills of increasing diameter, which can lead to low heat generation in the cortical and spongy bone. Thus, drill geometry plays a major role in heat production as unique relationships were observed between their temperature rise at the cutting site and cutting time.

Drill material/drill wear

The condition of the drill plays a role in regulating the temperature of bone during drilling. Much higher temperatures have been recorded when a worn drill was used. The sharpness of the drill was demonstrated to be a function of the number of uses, pressure, sterilization techniques, density of the sites, construction material, and surface treatment. According to Mahmut Sumer, the stainless steel drill tested in study generated less heat than the ceramic drill at initial drilling. However, there was no statistical difference in heat production between these two drills at deeper site. The reason for the greater heat initially might be the lower heat conductivity of ceramics in compare to steels. Due to this low heat conductivity, localized accumulation of heat might occur in the friction zone. In contrast, Koo had used three types of drills in study such as titanium nitride-coated metal, tungsten carbide carbon-coated metal, and zirconia ceramic drill to evaluate the effects of drill wear on bone temperature during osteotomy preparation and there was no significant difference between the drill materials. The TiN-coated drills (Steri-Oss and Paragon) showed significantly lower removal rates and greater wear than noncoated drills. The significant difference in temperature was noticed between the initial drills those had been used for 50 or fewer times and more than 50 times, irrespective of the drill material. Therefore, to minimize surgical trauma, well-sharpened drills are recommended.

Drilling load/speed/torque

Less number of literatures are there showing importance to the amount of pressure and the resulting frictional heat generated. Matthews and Hirsch conducted a study in which they reported that the temperature recorded was inversely
proportional to the drilling force. According to Brisman, the force applied on the handpiece was more influential than the speed of the drill in temperature elevation. They found that the drill speed was not the critical determinant of heat production, rather the difference in the drilling force was related to both the maximum temperature elevation and periods of temperature elevation. Increasing both the speed and the load together allowed for more efficient cutting with no significant temperature increase.[10] Abouzgia also suggested that drilling at a high speed and with a larger load was more efficient than using low speed and a lesser load.[12] In contrast, another study explained that gradual drilling induced less friction and less trauma to the bone as compared to conventional low-speed drilling took much longer duration time for drilling.[20]

**Single versus sequential drilling**

Drilling to widen the site to the exact diameter of the future implant can be performed either in one step or gradually. Study done by Benington showed higher heat generation with spiral drill during sequential drilling.[11] Gehrke had found that the single bur drilling protocol could not produce greater bone heating compared to the conventional protocol and may be considered a safe procedure. In contrast, study done by Lucchiari evaluated that the single-drill method induced a significantly greater variation in temperature than the traditional method, only when irrigation was used; without any irrigation, the difference in the temperature rise by the two methods was not statistically significant.[37] The use of a graduated series of drills to widen the site has been noticed as the procedure that results in only the removal of a small quantity of cortical bone, as the site has already been cut by the preceding bur in the series. Thus, single drill can be reliably performed without causing bone heating greater than that seen with standard sequential drilling techniques with required protocol.[46]

**Continuous versus intermittent drilling**

Whenever continuous drilling is performed, temperature will rise not only because of the lack of irrigation, but also due to the clogging effect of the bone debris on the cutting surfaces of the drill, which decreases its cutting efficiency and consequently increases the time required for bone bed preparation.[46] Strabac demonstrated that the highest temperature rise during implant osteotomies occurs during the withdrawing process which is influenced by predominant factors such as osteotomy depth and mode of irrigation. Clinicians should interrupt the drilling procedure at least every 5 s for at least 10 s and apply normal saline to the bone. This interruption will dramatically decrease the time the bone temperature is elevated.

**Conventional versus unconventional drilling techniques**

Nowadays in implant dentistry, considering the surgical and prosthetic points of view, the aim of all the procedures like computer-aided methods is the optimization of the implant’s position, to assure the optimum biomechanical, functional, aesthetic, and phonetic results, which minimizes the risk of surgical and prosthetic errors in implantology. A study done by Ferhat Misir evaluated that implant preparation using drill guides generates significantly higher temperatures compared to the classical preparation technique. This difference is due to the metal sleeves used in the drill guides which were not allowing irrigation fluid to reach the preparation sites while drilling.[19] More recently, special instruments for ultrasonic implant site preparation have been introduced. The main advantages of ultrasonic osteotomy include the selective cutting of hard tissue, the hemostatic effect on the surrounding tissue, and the generation of a gentle, precise cut without the need for excessive force. On other side, Dragana Gabric Panduric had done study to compare thermal changes after drilling with an Er: YAG laser versus a low-speed surgical drill. The temperature was statistically lower during the laser preparation. Cavities prepared with the laser were regular with clear sharp edges and knife-like cuts, with regular and sharp edges, without bone fragments and debris which resulted in lesser generation of heat in a shorter period of time. Thermal alterations in the treated surface were minimal.[20]

**Mode of irrigation**

Saline irrigation is mostly used for the prevention of the heat generation during osteotomy for the protection of the bone from the thermal damage. And also, most of the surgeons prefer cool saline solutions with the belief that they are more effective than the normal solutions for the reduction of the temperature. Benington had carried out study to compare the temperatures that were generated under external and internal irrigation systems during bone preparation for implants and observed that no statistical benefit was observed for one irrigant delivery system over the other. Gehrke had compared the results of the external irrigation technique with those of a double irrigation technique and result showed that the double irrigation technique produced a significantly lower rise of temperature in the cortical bone, which illustrated its greater efficiency compared with that of the external irrigation technique.[34] While on the other side Georg D. Strbac had evaluated the temperature changes during implant osteotomies between the combined irrigation system and commonly used external and internal irrigation under standardized conditions and concluded that an external irrigation method primarily reduces temperature during drilling in the superficial cortical bone areas even with an intermittent procedure, thus showing higher temperature generation in deeper cancellous bone areas with greater drilling depths. This study was able to demonstrate that an internal irrigation appears to be superior to a combined irrigation method during an intermittent graduated drilling osteotomy. In contrast, the use of combined irrigation primarily seems to be superior to an external irrigation method at greater
osteotomy depths.[35] Saline solutions at lower temperatures are more effective in cooling the bone, and lowering the temperature is said to have an anti-inflammatory effect at the operation site.

**Conclusion**

Within the limitations of this systematic review study, the following conclusions could be drawn:

- As bone is more susceptible to thermal injury and temperature more than 47°C can result in osteonecrosis, care should be taken for atraumatic surgical technique which can lead to least heat generation
- D1 type of bone is more dense, less vascularized, and contains little water, so thermoconductive rate is higher. Avoid excessive temperature generation during surgical drilling for D1 type of bone with interrupted drilling sequence and combine irrigation technique
- Drill design – Drill geometry can affect the cutting efficiency and heat generations. While compared to stainless steel drills, ceramic drills lead to more heat generation during initial drilling. In contrast, less heat is generated with repeated use of ceramic drills as its wear resistance is more than stainless steel
- Drill deformation is directly proportional to the number of times drills were used. According to literature, drills should not be used for more than 40 osteotomies. Therefore, well-sharpened drills are recommended to minimize surgical trauma
- A rise in temperature of bone can be caused by independently increasing either the speed or load. However, increasing both the speed and the load together allows more efficient cutting without significant rise in temperature
- The single drill method induces significantly greater variations in temperature than the sequential method, but only with irrigation, without any irrigation, the difference in temperature variation with both the techniques is not significant
- The guided surgery technique generated a higher bone temperature than the classic drilling technique
- The heat production during ultrasonic implant site preparation is higher than conventional drilling
- Er:YAG laser produces implant site preparation with regular and sharp edges, with lesser heat generation, without bone fragments and debris, and in a shorter period of time
- Any drill or drilling method generates higher heat without water irrigation. Coolant availability is the predominant factor in determining bone temperatures. Constant external irrigation with saline solution provides sufficient cooling at all drilling depths, while internal irrigation appears to be superior to a combined irrigation method during intermittent graduated drilling osteotomy. In contrast, the use of combined irrigation primarily seems to be superior to an external irrigation at greater osteotomy depth.

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**Conflicts of interest**

There are no conflicts of interest.

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