Factors Affecting Heat Generation During Implant Site Preparation: A Review of Biologic Observations and Future Considerations

Sherif H. Tehemar, BDS, MSc*

Atraumatic preparation of the recipient site has been considered an important factor influencing implant survival. Heat generation during bone drilling has been reported to be related to various factors. The methodology for heat assessment and bone examination together with the osseous models are still points of great speculation. The present paper classifies and discusses some of those factors in detail from both biologic and clinical perspectives. The methods of heat assessment and bone examination are reviewed, and the advantages and the limitations of each technique are presented. Future considerations based on clinical data reported are suggested.
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Key words: dental implant, heat generation, osseointegration, osseous models, thermocouple, thermography

Bone tissue is one of the more highly cellular and most richly vascularized structures in the human body. Previous studies have demonstrated that healing of the osseous structure can occur by 1 of 2 phenomena, repair or regeneration.[1] In implant dentistry, the progression of bone healing dictates the outcome of the implant.[2] Regeneration with future osseous integration of the implant is expected if certain surgical and biologic parameters are strictly followed.[3] Further analysis of the osseointegrative phenomena has revealed that this complex array of events may be threatened by frictional heat generated during implant site drilling.[4,5] In addition, it has been documented that the width of the necrotic zone that appears around the surgical defect is directly proportional to the magnitude of heat generated during the surgical procedure.[6]

Attempts have been made to assess the amount of heat generated during implant site drilling and to identify the critical temperature threshold above which osseous necrosis occurs.[5,7] Application of the results reported was found to be problematic because of different osseous models, variable methods of heat assessment, and alterable procedures of bone examination. In addition, numerous implant systems with their various armamentaria and particular applications of dental implants related to patient age, site, and bone density have significantly increased the number of variables associated with heat generation.

The aim of the present paper was to identify the possible factors that could affect heat generation during implant site drilling and to discuss the research methodologies applied, as well as future considerations.

Reaction of Bone to Thermal Injury

Heat has been reported to impair the turnover activity of bone tissue by causing hyperemia, necrosis, fibrosis, osteocytic degeneration, and increased osteoclastic activity.[8–10] Previous studies have reported that temperatures ranging from 56°C to 70°C are deleterious to bone tissue because alkaline phosphatase (AP) is denaturated at that level.[11–14] Recently, in a series of studies carried out by Eriksson, Albrektsson, and colleagues,[4,5,7] it has been demonstrated that bone is

*Postdoctoral Fellow, Department of Oral Biology and Anatomy, School of Dentistry, Medical College of Georgia, Augusta, Georgia; Assistant Lecturer, Department of Oral Surgery, Faculty of Dentistry, Alexandria University, Alexandria, Egypt.

Reprint requests: Dr Sherif H. Tehemar, 22 Portsaid St., Apt. 10, Chatby, Alexandria, Egypt.

Table 1 Some In Vitro Studies of Heat Assessment

Authors	Osseous models	Irrigation method	Drills	Observations
Rafel[18]	Human mandible*	None	Surgical burs (high speed)	Intermittent cutting with cooling results in less heat
Matthews and Hirsch[11]	Human femoral bone blocks	External	Surgical drills	The forces applied are more important than drilling speed
Hobkirk and Rusiniak[19]	Young bovine mandibular bone blocks*	External with 0.9% saline	Different surgical bur	Interoperator differences are a factor
Lavelle et al[10]	Human femoral bone blocks*	Internal with normal solution at rate of 500 mL per minute	Two different designs of steel burs	Internal irrigation reduces heat more than does external irrigation
Krause et al[20]	Bovine femoral blocks*	None	Orthopedic drills and saws	Feed rate and depth are factors
Watanabe et al[21]	Pig cortical ribs†	With and without irrigation (internal and external)	Different systems (IMZ, ITI, and Brånemark	Shape of the drill and the site are factors
Sutter et al[22]	Calf humerus*	Internal and external	ITI system	Internal irrigation reduces heat generation
Jo et al[23]	Bovine femoral bone*	External	Different systems	Load and drill design are not factors
Yacker and Klein[24]	Bovine cortical bone blocks*	External	2-mm bur	Bone density is more important than drilling depth
Brisman[25]	Bovine femoral bone blocks*	External	2-mm pilot 2.5-mm spade 3.25-mm spade	Increasing speed and load result in efficient cutting with less heat
Benington et al[26]	Bovine mandibular cortical bone†	None	Round, spiral, and pilot drills	Drill design is a factor
Cordioli and Majzoub[27]	Bovine femoral bone blocks*	External	Twist and triflute drills of variable diameter and length	Drill design is a factor

*Temperature recorded by thermocouple technology.
†Temperature recorded by infrared thermography.

more sensitive to heat than previously believed, and it will withstand a threshold temperature ranging from 44°C to 47°C for only 1 minute without impaired bony regeneration. In their first article, Eriksson et al[4] concluded that temperatures below the denaturation point of AP (53°C) could be considered harmful to the reparative capability of bone, as burning and resorption of fat cells together with sluggish blood flow were observed. Using the same technology for evaluation that involved the growth chamber, Eriksson and Albrektsson[5,7] reported in their studies that heating up to 47°C was considered the optimal limit that bone can withstand without necrosis. From a mechanical standpoint, heat was reported to induce dislocation in the hydroxyapatite mineral lattice structure, to the extent that microscopic deformation (creep) of compact bone could be observed.[15–17] This latter observation could explain, in part, implant mobility in the samples heated for 50°C for 1 minute reported in a previous study.[7]

Osseous Study Models

Different osseous models utilized for recording temperatures during implant site drilling include dead specimens, live animals, and humans; nevertheless, most of the data available are based on dead tissues. (The in vitro and in vivo studies are cited in Tables 1 and 2.) There is a great difference between dead and living bone in terms of actual density and cellularity,[34] water content, fluid movement,[14,35] and thermal conductivity.[36] These variables could explain the higher thermal conductivity of blood versus bone[37] and may indicate why the bone viability is not jeopardized when temperature above the critical level has been reached in some studies.[38–42] However, the use of dead specimens is advantageous for testing pressure and other mechanical aspects that could be impossible to test otherwise.

While it could be beneficial to assess heat generated based on vital animal models, this approach appears to be impossible because of ethical and legal concerns, especially when using "traumatic" techniques such as thermocouples or biopsies.

Table 2 Some In Vivo Studies of Heat Assessment and Bone Examination

Authors	Osseous models	Examination methods	Irrigation method	Main observations
Cotisch et al[28]	Canine mandible	Histology and radiography	With and without	High-speed with coolant is better than conventional speed
Spatz[29]	Canine mandible	Histology	None	High-speed produces earlier, more rapid cutting without much necrosis
Hall[30]	Guinea pig's leg	Histology	None	No bone necrosis recorded
Agren and Arwill[31]	Rabbit leg	Histology and radiography	None	No difference between conventional and high-speed cutting
Eriksson et al[4]	Rabbit tibia	Thermal chamber	None	At 53°C irreversible damage to bone occurs
Eriksson and Albrektsson[5]	Hares and rabbit	Thermal chamber and thermocouple	External with saline	47°C is the critical temperature level
Eriksson and Albrektsson[7]	Rabbit tibia	Thermal chamber and thermocouple	External with saline	No bone injury at 44°C for 1 minute; 47°C or 50°C results in damage of bone
Eriksson et al[32]	Rabbit femur and fibula	Thermal chamber, histology, and histochemistry	External with saline	Thermal chamber is better for tissue examination than histochemistry or histology
Eriksson and Adell[33]	Humans	Thermocouple	External with saline	Maximum temperature should be 30.3°C for 5 seconds
Haider et al[34]	Sheep	Histology and histochemistry	External and internal	Additional external irrigation is advantageous and spongy bone tolerates heat better

Thus, there is a shortage of data in the dental literature. However, recent developments in thermographic technology (infrared and real time thermography), considered to be "atraumatic," might lead to human applications in the future.

Instruments for Heat Assessment

The methods used to record temperature rise include either direct recording by thermocouple instruments[24,33] or indirect estimating by infrared thermography,[21,26] mathematic calculation,[43] or by measuring the electrical power supplied to the drill.[44] Thermocouple technology implies the placement of heat-sensitive elements in bone specimens connected to thermometers or special computer software. Despite its popularity, thermocouple results are usually governed by numerous factors that may render future comparison somewhat questionable. These include:

1. Material of the sensor element
2. Number and size of the hole
3. Degree of error
4. Depth of recording
5. Distance from the point of recording
6. Number of elements inserted
7. Dimension of the dead specimen
8. Element isolation technique
9. Type of model (vital/dead)
10. Density and vascularity of tissue

In addition, there have been concerns regarding thermocouple ability to detect only spot temperature, rather than overall thermal profile[26] and the heat leakage that occurs through the holes. Another limitation reported is the technical difficulty frequently encountered during insertion of the elements very close to the drill.[27]

Infrared thermography is a technology based on the detection of energy emitted by electromagnetic radiation. As this energy is dependent on the temperature of the body examined, accurate determination of the temperature could be made.[45] In implant dentistry, this concept was introduced by Horch and Keiditisch in 1980.[46] D'Hodet et al[47]

Table 3 Factors Affecting Heat Generation During Implant Site Drilling

Operator	Manufacturer	Site	Patient
Drilling pressure	Drill design	Cortical thickness	Age
Drilling status	Irrigation system	Site condition	Bone density
Drilling motions	Drill sharpness	Drilling depth	
Drilling speed	Implant systems		
Drilling time			

used this technique to compare the heat generated by different implant systems. Recently, this technique was reported to be more accurate than using the thermocouple, because it allowed an overall assessment of the heat, did not require bone drilling, and possessed a smaller degree of error than the thermocouple.[26] While it is limited in clinical use mainly because of its high cost,[48] technical experience is usually required,[48] and the procedure cannot be utilized in conjunction with irrigation.[26] With lack of sufficient documentation and comparative studies, preference is difficult to determine.

Factors Affecting Heat Generation During Implant Site Drilling

Generally, the amount of frictional heat generated is directly related to the magnitude of force (pressure), size and shape of the drill, and the time of drilling. In addition, although intimate contact between the drill and bony wall is mandatory, it is usually considered the main reason for heat generation. The factors affecting the development of frictional heat are classified and summarized in Table 3.

Factors Related to the Operator

Pressure Applied to the Drill. Little attention has been given to the amount of pressure the operator places on the handpiece and the resulting frictional heat generated. While Eriksson and Adell[33] advocated using low hand pressure, the magnitude of this pressure was not specified,[25] perhaps because the force applied cannot be standardized because of the human factor.[19] Using human cortical femoral bone, Matthews and Hirsch[11] conducted a study in which different forces (pressure) and speed were evaluated. They reported that the temperature recorded was inversely proportional to the drilling force. Brisman recently reported similar findings using bovine femoral bone.[25] The experiment was designed to place weights on a surveyor to provide a constant steady vertical force on the handpiece ranging from 1.2 to 2.4 kg, with bur revolutions extended from 1,800 to 2,400 rpm in all possible combinations. He observed that when greater force was placed on the handpiece and the speed was kept at 1,800 rpm and/or when drill speed was increased and light pressure of 1.2 kg was maintained, greater heat was generated. Consequently, he concluded that the force applied on the handpiece was more influential than the speed of the drill in temperature elevation.

In contrast, Abouzgia and his colleagues[44,49–51] suggested that drilling at a high speed and with a larger load was much more desirable than using low speed and a lesser load. In one experiment, less temperature was always recorded with the use of high force and speed.[50] In another experiment monitoring the electric power supplied to the drill, an increase in the power was always associated with lesser speed or higher force.[44] Consequently, Abouzgia concluded that the decrease in temperature rise could be attributed in part to the decreased time needed for cutting when using larger force and higher speed.[51] Further investigations are needed to clarify this issue.

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.

Graduated Versus One-step Drilling. Drilling to widen the site to the exact diameter of the future implant can be performed either in one step or gradually. One-step drilling has been recommended for the placement of screws for plate fixation using a single-twist drill running at a speed of 20,000 rpm to prepare the site to the final diameter of the screw.[52] In contrast, the use of a graduated series of drills to widen the site has been recommended by the Scandinavian osseointegration group,[3–5,7,32,33,52–54] and it was noted that this procedure 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. The in vivo study conducted by Eriksson and Adell[33] on human and animal models clearly illustrates this concept.

Intermittent Versus Continuous Drilling. Drilling into bone involves the use of irrigation, either internal or external, to reduce the heat generated. Because of the intimate contact present at the bone-drill interface, the irrigation solution has to reduce the temperature throughout the whole length of the bony walls. This mechanism could not be achieved unless the bur or drill was intermittently removed to allow the escape of bone chips and access for the irrigation fluid. Whenever continuous drilling is performed, temperature will rise not only because of the inaccessibility of cooling fluid, but also because of the clogging effect of the bone debris on the cutting edge of the drill, which will decrease its cutting efficiency and consequently increase the time required for bone bed preparation.[24,33,53] Watcher and Stoll[37] confirmed this hypothesis and reported that by applying intermittent load the mean temperature recorded decreases, regardless of the pressure applied.

Drilling Speed. Different clinical and experimental studies have been conducted to evaluate the role of drilling speed[55–58]; however, this issue is still being debated. Agren[31,59] and Agren and Arwill,[60] as well as others,[28,57,58] have reported no substantial difference between the healing and bone repair in defects produced with different speeds as monitored in dogs and rabbits. In contrast, other investigations have found that slow rotational speed frequently reduces or limits frictional heat arising from bone drilling.[39,61–64] Nevertheless, different factors could contribute to such contradictory findings, such as the study models, site of drilling, type of drill used, and methods of examination; the actual running speed should also be considered. Recently, it has been postulated that neither the manufacturers' stated speed nor the measured free-running speed could match the actual speed of the drill, as reduction in the drilling speed during cutting (up to 50%) can occur.[44,49] Further investigations are required to clarify this issue.

In implant practice, the evidence-based recommendation of Eriksson and Adell[33] seems to be the most applicable at the present time. They have demonstrated that high-torque, low-speed handpieces running between 1,500 and 2,000 rpm (which results in minimal temperature rise and sufficient drilling accuracy) are considered the ideal instruments for implant bed preparation.

Time. Time can be considered as the time of drilling, or the time required for the heated part to return to its normal temperature. The time of drilling is always directly proportional to the amount of frictional heat generated. The early report of Eriksson and Albrektsson[5] demonstrated that the long-term effect of heating bone up to 47°C for 5 minutes resulted in dominant bone resorption (about 20%) after a period of 30 days. This was accompanied by an invasion of fat cells and little osteogenic activity. Previous studies using high-speed rotary instruments have demonstrated that the significant decrease in drilling time may explain the decrease in temperature rise with the use of high-speed drills.[18]

Recently, Brisman[25] evaluated the effect of timing on bone temperature using bovine femoral cortical bone. Two times were monitored in this experiment: the time required to drill a 7-mm hole, and the time until maximum temperature elevation was reached. Use of testing several possible combinations of pressure and speed revealed that less time was recorded when bone cavities were prepared at 2,400 rpm with 2.4 kg of load and resulted in a marked decrease in temperature than other combinations tested in the study. However, a temperature lower than the critical level (47°C) was recorded using 1,800 rpm and 1.2 kg, without a significant decrease in time. Cordioli and Majzoub have reported that the load applied by the operator during cutting on human bone usually falls in the range of 2.0 kg with a speed not exceeding 2,000 rpm.[27] Those parameters tested as a control group in Brisman's study have demonstrated a temperature less than 47°C (critical level), which is in accordance with the osseointegration protocol.[5,7,32]

Regarding the second issue, Cordioli and Majzoub[27] concluded that the depth of the cavity, its diameter, and the flute geometry of the drill contributed to the time required for the maximum temperature to return to normal. However, further investigation is required to support this hypothesis.

Manufacturer-Related Factors

Drill Design and Flute Geometry. Root-form implants vary considerably in design for biologic and mechanical reasons. Because the end result of the drilling cascade has to be a recipient bony bed of the same diameter and shape of the proposed implant, the drills usually follow the morphologic and topographic skeleton of the implant. With the great variety of dental systems commercially available, comparison between the different designs and shapes of drills seems to be impossible.

In general, twist drills and taps are used to prepare sites for screw-shaped implants, and triflute drills are used to prepare sites for cylindric implants.[65] Investigations performed on animals[66] and human bone,[11] as well as others,[67,68] have demonstrated that flute geometry and drill design contribute to the temperature rise during drilling. Cordioli and Majzoub[27] compared the different types of drills on heat generated in bovine bone blocks. They reported that a triflute drill 4 mm in diameter generated less heat than 2- and 3-mm twist drills and a 3.3-mm triflute drill, regardless of the cavity depth. However, the higher ranges recorded, compared to previous investigations,[21,33] may be attributed to the different models and to the load applied during drilling.

A 4-flute drill has recently been introduced to reduce frictional heat, although Kay et al[65] recommended that the maximum number of flutes that could withstand use without technical problems was 3; this issue has not yet been resolved. In addition, as the triflute drill theoretically generates less heat than the twist drill, one can assume that cylindric implants should have more predictable survival rates than screw-type implants. However, clinical studies have failed to detect such a difference between the 2 designs.[69,70]

Irrigation Systems. Two types of irrigation systems are frequently utilized: internal and external. Comparative in vitro studies have demonstrated that without irrigation, a temperature above the critical level is usually reached.[24,27] In 1974, Huhule[71] proposed an internal cooling system to be used during the ostectomy procedure. He concluded that this method of cooling had several advantages over external irrigation. It prevents clogging of the drill flutes by bone chips, and its efficacy is maintained regardless of the depth of the cavity.[72,73] Confirmatory findings were later reported by Kirschner et al[74] and Schmitt et al.[75]

Despite the promising results reported using internal irrigation systems, this issue requires further study.[24,27] The only report present in the international dental literature is that of Haider et al.[34] In their histologic and histochemical study, this group demonstrated that additional external cooling seemed to be beneficial for any internal system, particularly in compact bone.[34] While the latter study was conducted mainly to observe the healing pattern of bone using a variety of cooling systems, and not to monitor the thermal change in the irrigation systems, it demonstrated, for the first time, the biologic reaction of bony structure to the cooling system. However, future in vivo investigations of the effect of internal irrigation as well as the use of chilled irrigant would be advantageous.

Sharpness of the Cutting Tool. The condition of the drill plays a role in regulating the temperature of bone during drilling.[62] Much higher temperatures have been recorded when a worn drill was used.[11] 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.[24,66] Previous analysis using scanning electron microscopy revealed tangible wear on the cutting edges of trephine drills after 12 to 18 milling procedures.[22] Although the number of sites to be prepared before drill change is usually suggested by some manufacturers, visual examination or the observation of when the drill fails to progress rapidly, frequently indicate the need for a new drill.

Diameter of the Drill. Careful review of published data reveals that less heat usually accompanies drills of larger diameter compared to smaller ones. One study demonstrated that the time required for the temperature to return to baseline was twice as long for a 2-mm as compared to a 3.3-mm diameter drill.[27] Yacker and Klein[24] reported that a 2-mm bur produces less heat compared to a 3-mm bur, even with an increase in depth. It can be concluded that the amount of bone to be cut by the 3-mm drill (1 mm) was less than that cut by the preceding drill (2 mm), which may explain the smaller amount of heat generated using a larger diameter drill.[24] Similar findings were reported by Watanabe et al[21] with use of the cannon drill of the IMZ system. Consequently, it seems that the amount of bone to be removed is more critical in terms of heat generation than the diameter of the drill, and therefore it is the diameter of the initial bur or drill that deserves greater consideration.

Most of the implants used for patient rehabilitation fall within the range of 3.25 to 4 mm in diameter. Currently, some reports have been published on the mechanical and clinical advantages of wider implants (5 to 6 mm).[76] There have been recommendations that those wide implants may behave more predictably in certain clinical situations.[77] However, all of the documented data available are based on the standard diameters.

Factors Related to the Recipient Site

Cortical Thickness. For an implant to be stable, it should engage cortical bone at each site prepared.[78] However, in cancellous bone the maximum vascular penetration rate has been established as 0.5 mm per day, compared to 0.05 mm per day in cortical bone.[54] Thus, the healing ability and thermal conduction seem to be better in cancellous bone, while cortical bone is better for initial implant stabilization, especially in the very early stages of healing. This concept has been questioned by Haider et al,[34] who reported that less and later new bone formation took place when implants were in close contact with the bony bed, compared to areas with a wide gap. With this complex concept, the effect of temperature had been monitored mainly in cortical bone (Table 1), thus class I and class II bone only. Future studies should be performed to confirm the minimal results reported for cancellous bone.[34,79]

Healed Versus Healing Site. In the last few years, considerable attention has been given to the placement of dental implants in fresh extraction sites so as to reduce treatment time and take advantage of the reparative process of the extraction socket.[80,81] Some authors maintain that less heat will be generated during implant drilling in a healing site than in a healed site.[82,83] Actually, an extraction socket is usually larger in diameter than that of the proposed future implant because of the expansion phenomenon associated with the extraction procedure. Thus, the drill will usually engage only the apical portion of the socket, which can markedly reduce the amount of frictional heat. Although this concept seems to be accepted, it has not been scientifically proven.

Drilling Depth. Depth of the recipient site is usually determined by several factors. The effect of drilling depth and frictional heat has received attention from different authors.[34,65] Cordioli and Majzoub[27] reported a significant increase in temperature at depths of 8 mm versus 4 mm, regardless of the diameter of the drill used. However, it seems that the type of irrigation used greatly affects temperature rise at the deepest level, rather than the depth of the site itself.

Factors Related to the Patient

Age. Dental implants were used initially for rehabilitation of geriatric patients (complete edentulism). Now, their application has been extended to involve partially edentulous situations and single-tooth replacement. It has been well documented that in older patients, certain physiologic changes occur. Bony structures tend to become more dense and more fragile; the medullary cavity space enlarges faster, resulting in a net decrease of cortical thickness and mass; and healing capability is usually impaired. In addition, bone aging is characterized by increased crystallinity of the bone mineral matrix, corresponding to an increase in size and improvement in the chemical perfection of the apatite crystals.[84–86] Although some features of bone have been evaluated in terms of heat, the effect of heat in relation to age has not been studied.

Bone Density and Texture. 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[24] reported that bone density is a far greater indicator of bur temperature than depth of the osteotomy. Their conclusion was based on an in vitro study conducted on bovine bone blocks, in which marked differences in temperature were seen between cortical and cancellous, regardless of depth of the drilling cut. For instance, when drilling at 8.5, 18.5, and 20.5 mm, drill temperatures were 54.0°C, 51.9°C, and 115.8°C, respectively (in cortical bone). However, the temperature decreased from 49.5°C to 39.3°C even when the depth increased from 10.5 to 15.5 mm (in cancellous bone). However, future studies are necessary to resolve this issue.

Biologic Observations

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, a process that may take months to be accomplished. This reparative phenomenon is usually dependent on the cellular and vascular status of the bone rather than the effect of the drilling tools, although this point needs further clarification. It has been our observation that nearly all the biologic testing has been done in either dead bone (mostly histologic and physical assessment), or through vital examinations through thermal chambers (which lack the assessment of drilling and tapping effect on the cellular components of bone). Site preparation parameters seem to need further assessment.

Future Considerations

The relationship between heat generated and implant placement via the drilling ostectomy is multifactorial in nature and its complexity has not been fully realized. Despite the significant development in the field of microscopic and diagnostic technologies, a shortage of scientific knowledge regarding this issue still exists. By reviewing the scientific literature, it is apparent that certain questions remain unanswered.

1. What is the optimal geometric design for a drill to minimize heat generation?
2. Are healing sites better than previously healed sites from the heat effect standpoint?

3. Is an internal irrigation system more efficient than an external one in terms of heat reduction?
4. Will the use of other diagnostic tools to evaluate the biologic reaction of bone structure to drilling be useful?
5. With the increase in implant placement in the maxilla, what is the effect of heat generation in cancellous bone? Should drilling speed be changed?
6. With the great variation in bone density, should pressure and speed of the drill be changed according to the bone density and age of the patient?
7. Does the heat recorded vary when drilling in regenerated bone?

With great respect to all of the previous studies, available documentation in the dental literature is still incomplete.

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