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Thermal irritation of teeth during dental treatment procedures

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While it is reasonably well known that certain dental procedures increase the temperature of the tooth's surface, of greater interest is their potential damaging effect on the pulp and tooth-supporting tissues. Previous studies have investigated the responses of the pulp, periodontal ligament, and alveolar bone to thermal irritation and the temperature at which thermal damage is initiated. There are also many *in vitro* studies that have measured the temperature increase of the pulp and tooth-supporting tissues during restorative and endodontic procedures. This review article provides an overview of studies measuring temperature increases in tooth structures during several restorative and endodontic procedures, and proposes clinical guidelines for reducing potential thermal hazards to the pulp and supporting tissues. (*Restor Dent Endod* 2013;38(3):105-112)

Key words: Light curing; Root canal obturation; Thermal irritation; Tooth preparation; Ultrasonic

Introduction

It is commonly believed that various dental procedures, such as tooth preparation, composite resin restoration, and root canal obturation, can cause temperature increases on the teeth surfaces. However, the question of "to what extent does the temperature increase cause actual damage to the pulp and tooth-supporting tissue?" is difficult to answer. This concern can be addressed by two questions: (a) "what is the range of safe temperatures that will not cause thermal damage such as inflammation or necrosis to the pulp and tooth-supporting tissue," and (b) "what is the objective extent of the temperature increase during various dental procedures"?

Previous *in vivo* studies about the range of safe temperatures have reported varied results, indicating that the range of safe temperatures is not accurately known. Often cited is Zach and Cohen's *in vivo* study on monkeys, which reported that an intrapulpal temperature increase of 5.5℃ caused pulpits or pulp necrosis in 15% of irritated teeth.[1] Regarding alveolar bone or periodontal ligament, the study of Eriksson and Albrektson reported that a temperature increase of 10℃ on the outer root surfaces caused bone resorption and tooth ankylosis.[2] These two studies have been widely cited as a reference for threshold temperatures that will not cause thermal damage to the pulp and tooth-supporting tissue.

Regarding the objective extent of the temperature increase during various dental procedures, the results vary from previous *in vitro* or *in vivo* studies measuring intrapulpal or tooth-surface temperature increases. When tooth preparation was conducted using high- and low-torque handpieces, the tooth surface or intrapulpal temperature increases were approximately 0.8 - 3.0℃.[3,4] The maximum intrapulpal temperature increase was 7.8℃ when the composite resin was photopolymerized,[5-7] and was 3.4 - 12.3℃ during fabrication of direct provisional crowns with acrylic resins.[8,9] Apart from restoration procedures, in endodontic procedures, the temperature increase of the root surface could affect the periodontal ligament or the alveolar bone; for example, thermoplasticized canal obturation can cause temperature increases on the root surface of approximately 6.5 - 22.1℃.[10-12] The temperature increase of root surfaces is especially high when using ultrasonic devices in post or file removals, with a maximum rise of 40.4℃ on root surfaces.[13-15]

The reason for the variation in the range of temperature rise is not only because experimental factors such as the measuring method, influence the results but also because many factors such as the remaining dentin thickness, type of handpieces used, light curing unit, type of ultrasonic device, or water spray used will affect the temperature. In addition, it can be speculated that the temperature increase of an actual patient's pulp and surrounding tissues can be lower than that suggested by *in vitro* research, because thermal dissipation by pulpal, periodontal, and osseous circulation plays an important role.[5]

Despite this, according to the results of many studies, there is a need for dental clinicians to gather sufficient knowledge on thermal irritations during dental procedures that may potentially affect the pulp and surrounding tissues of teeth so as to minimize the occurrence of damage. Therefore, this review article aims to look at the temperature rise that occurs during several dental procedures and suggest some clinical guidelines to minimize the damage to the pulp or the surrounding tissues due to thermal irritations.

Review

Response of pulp and supporting tissue to thermal irritation

Although external stimuli such as 'thermal irritation' can damage pulp tissue or at least cause changes in the pulp tissue, a direct correlation is not always found between the measured temperature and the actual tissue damage.[16] Further, in clinical situations, it is quite difficult to judge the cause of pulpitis, because the removal of a tooth structure is accompanied by physical damage as well as thermal irritation.[1]

In an *in vivo* study on monkeys, Zach and Cohen carried out histological observation of the pulp tissue on 2, 7, 14, 56, and 91 days after the imposition of thermal irritation using a soldering iron on the surface of teeth to determine the pure effect of thermal irritation on physical damage.[1] A thermistor was installed in the pulp chamber of teeth on one side of the arch to measure the temperature rise, and the same thermal stimulation was applied on the opposite side of the arch. An intrapulpal temperature increase of 5.5℃ for 10 seconds caused histological changes in the pulp tissues, approximately 15% of which were irreversible pulpitis.[1] When the intrapulpal temperature increase was sustained at 11.1℃ for 10 seconds, there was approximately 60 - 70% irreversible pulpitis.[1] The mechanism of pulp necrosis by thermal damage can be defined as the 'burn reaction', which includes blister formation, destruction of ectopic odontoblasts, protoplasm coagulation, expansion of liquid dentinal tubules, and an increase of inward flow. This affects the internal blood vessels and leads to vascular injury, which ultimately results in pulp necrosis.[1]

On the other hand, in a more recent *in vivo* study on human teeth, transient temperature increases of approximately 8.9 - 14.7℃ (mean, 11.2℃) did not cause pulp damage.[17] Although the testing method using a thermal resistor for stimulus and measuring intrapulpal temperature in the *in vitro* tests was identical to Zach and Cohen's previous work, variations on the speed and duration of thermal stimulus were made. The duration of the impulse was chosen on the basis of a symptomatic criterion, i.e. it was maintained for about 30 seconds after the patient reported that the stimulus had become painful.[17] Similar to clinical situations, a gradual temperature increase over approximately 200 seconds was simulated and the tooth was evaluated both clinically and histologically.[17] However, it did not result in clinical or histological evidence of pulp damage by an intrapulpal temperature rise of 8.9 - 14.7℃ within 68 - 91 days.[17] Therefore, it can be speculated that speed and duration of thermal stimulus as well as the extent of temperature rise plays an important role in pulp damage and gradual temperature increase may raise the threshold temperature rise higher than 5.5℃. However, the another important factor affecting intrapulpal temperature rise is residual dentin thickness, and with situations involving tooth preparation and light curing of composite resin, where the occurrence of heat takes place where the residual dentin is thin, this could impose a more dangerous situation.[16] On the other hand, in actual clinical situations, owing to thermal dissipation by pulpal, periodontal, and osseous circulation, in addition to increases in pulpal circulation by a nervous reflex, it can be assumed that intrapulpal temperature increases tend to be lower than *in-vitro* situation.[5,17]

Thermal damage is not limited to pulp tissue. Some endodontic procedures cause temperature increases on the outer root surface, which may result in potential damage to the root cementum, periodontal ligament, and alveolar bone.[2,18] There are several studies that propose a threshold temperature that can damage the tooth-supporting tissues.

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It was believed that the threshold temperature increase for alveolar bone is 19℃, because alkaline phosphatase is denatured at this temperature increase.[19] However, according to some later studies, temperature increase below 19℃ could also cause alveolar bone necrosis,[2,20] and the most referenced study showed that alveolar bone tissue was resorbed without signs of subsequent regeneration if temperature increase of bone was 13℃ for 1 minute or 10℃ for 5 minutes.[2] Following thermal damage, the healing of bone tissue was not through hard-tissue formation, but through the induction of connective tissue, suggesting that the threshold temperature increase for bone damage was 10℃.[2] Sauk *et al*. reported an even lower threshold temperature increase, and suggested that when the temperature increase of periodontal ligament was 6℃, there was protein denaturation and consequent ankylosis and alveolar bone resorption.[20] According to some *in vivo* studies, although an exact temperature was not specified, when thermal irritation was introduced to the endodontic wall, local necrosis, bone resorption, and ankylosis was found on the periodontal ligament.[18,21]

Tooth-supporting tissue is not limited by space and has a greater abundance of blood supply than pulp tissue. Therefore, the threshold temperature increase of 10℃ for tooth-supporting tissue is comparatively higher than that of 5.5℃ for the pulp. However with the increased use of the thermoplasticized obturation method, and ultrasonic devices in endodontic treatment, it is common that local temperature increases of the root surface exceed threshold temperature increase. Therefore, clinicians will need to take care not to cause thermal damage to tooth-supporting tissue, especially in the danger zone, where the residual dentin is very thin.

Thermal irritation during various clinical procedures

1. Tooth preparation with high- and low-torque handpieces

Because dental procedures use handpieces for removal of tooth structures very routinely, the high- and low-speed handpiece devices are the most frequently used ones. The friction between the bur and the tooth structure produces heat, which is why a water spray or an air spray should be used.

An *in vitro* study measuring intrapulpal temperature increase with a 0.5 mm residual dentin thickness, found temperature increases of 1.8℃, 1.4℃, and 0.7℃, with the low-speed handpiece, high-speed handpiece, and laser, respectively.[3] There were no statistically significant differences between low-speed handpiece and high-speed handpiece groups, but with the laser group, there was a significant observation with a low temperature rise. All three tools were used with water cooling for tooth preparation, and if the water cooling is done sufficiently, the temperature increase would be lower than the threshold temperature during tooth preparation.[3]

In a study by Srimaneepong *et al.*, tooth preparation was done using the laser and the high-speed handpieces at residual dentin thickness of 2.0, 1.5, 1.0, and 0.5 mm, and the pressure on the pulp and the internal temperature were measured.[4] The study showed that the thinner the residual dentin thickness and the higher the power of the laser, the higher was pulp pressure and temperature increase. When using a laser for removal of normal tooth structure, a lower temperature rise was observed than that with a high-speed handpiece.[4] However, even the highest temperature rise was 0.8℃, which was not a matter of concern with sufficient water cooling.[4] A study by Watson *et al*. showed similar results, and used water cooling with high- and low-speed handpieces to remove the tooth structure, and a surprising decrease in the internal temperature was observed.[22] The type of burs used could affect the temperature increase; as compared with the carbide bur, the diamond bur leads to a higher temperature increase, but the effect was not significant because of water cooling.[22]

Therefore, it is unlikely that tooth preparation, using high-speed or low-speed handpieces under water cooling, causes pulp damage because the observed temperature rise is comparatively low. However, dentists occasionally remove deep caries using a low-speed handpiece without a water spray. When cavities are cut dry, the intrapulpal temperature rise could exceed threshold temperature increase of 5.5℃ suggested by Zach and Cohen resulting in pulp damage.[1,23] According to Attrill *et al.*, the maximum intrapulpal temperature rise recorded for teeth prepared without water spray was 24.7℃, as compared with that of 3.9℃ in teeth prepared with water spray.[23] Another study also showed that when a low-speed handpiece is used without water spray, the intrapulpal temperature rise reached the threshold temperature increase of 5.5℃ within 20 seconds after the bur contacts tooth surface, whereas intrapulpal temperature decrease of 6.5℃ was observed when a low-speed handpiece is used with water spray.[1] In conclusion, in order to decrease thermal damage to the pulp during tooth preparation, it is necessary to use the handpiece with water cooling, and if it is used in dry cut, it is important to limit the bur contact time within 20 seconds.

2. Light curing of composite resin

Light-cured composite resin is a commonly used restorative material, and has an advantage of reducing the amount of tooth preparation for adhesion to tooth structures. However, the biggest disadvantage of the composite resin is shrinkage and heat production during polymerization. The temperature rise during visible light curing of composite resin is caused by both the exothermic reaction process and the radiant heat from the light curing unit (LCU).[5] Therefore, there are many studies that measured the temperature rise during light curing of composite resin and reported contributing factors.

Factors that affect the temperature rise during light curing include the type of LCU, curing light intensity, curing time, curing technique, type of composite resin, amount of composite resin, remaining dentin thickness, and presence of thermal barrier layers.[7] Generally, the heat generated from the LCU has greater affects than the heat from the exothermic reaction of composite resin, so the type of LCU, and the curing light intensity plays an important role in intrapulpal temperature rise.[7] Hannig and Bott measured intrapulpal temperature during light curing of composite resin using different types of LCU and a range of light intensity.[6] The results showed a highest intrapulpal temperature rise of 7.8℃ with Plasma arc curing (PAC) system followed by Halogen with intrapulpal temperature rise of 7.3℃, light-emitting diode (LED) system with that of 6.9℃, which were significantly higher than conventional curing unit Heliolux II with that of 2.9℃.[6] However, same type of LCU using different light intensity produced more differences in intrapulpal temperature rise, which means that the light intensity of LCU is more important factor than the type of LCU.[6] When the same LCU was used both in the 1-step mode (40 seconds curing with 730 mW/cm^2) and 2-step mode (10 seconds curing with 100 mW/cm^2 followed by 30 seconds curing with 730 mW/cm^2), the 2-step mode resulted in a lower temperature rise with statistical significance.[6] Of interest is that the maximum temperature rise was higher than 5.5℃ when composite resin was light cured, with highest light energy in residual dentin thickness of 1 mm. Another study using different types of LCUs reported that the temperature rise was only 1.3 - 2.7℃, even though it agrees with the results in which higher light intensity produced a higher temperature increase.[24] The two studies had the requisite 1-mm thick residual dentin, composite resin thickness of 2 mm, curing distance of 1 mm, so they are relatively comparable, but there was a difference in the teeth type: human and bovine teeth. Yazici *et al*. also used different types of LCU and reported that the highest intrapulpal temperature increase of 3.8℃ with Halogen system was observed followed by PAC (2.4℃) and LED (2.1℃).[25] Even though it is clear that type and light intensity of LCU affects intrapulpal temperature rise, it is somewhat controversial whether temperature rise during light curing of composite resin is enough to cause pulpal damage.

Apart from the type of LCU, the type and thickness of the composite resin and the residual dentin thickness also can affect the temperature increase. Matalon *et al*. measured the temperature increase beneath composite resin using different types and thicknesses of composite resin with different types of LCU and curing distances.[16] The study showed the higher the light intensity, the shorter the curing distance, and the thinner the composite resin thickness, the higher the temperature rise. In addition, a higher temperature increase occurred with microhybrid composite than with nanofiller hybrid composite.[16] Of interest is that the thinner the composite resin thickness was, the higher the temperature rise was. This can be explained by the fact that the composite resin acts as an insulator rather than heat generator from an exothermic reaction.[16] Thus, considering the insulating role of the composite resin, intrapulpal temperatures might be highest during application of light-curing bonding agents in the area of thinnest residual dentin.[5] Jacubinek *et al*. used finite element analysis to investigate the effect of the light intensity, curing mode, remaining dentin thickness, and existence of thermal barrier on the intrapulpal temperature rise, and found that the light intensity and curing mode had a bigger impact on the temperature rise than other contributing factors.[7] The role of the composite resin as an insulator was also emphasized.[7]

In conclusion, it is important to recognize that overcuring, using higher light intensity is potentially dangerous, and it is recommended that a thermal insulation layer of at least 1 - 2 mm thickness, such as glass ionomer cement, is needed in deep cavities with less than 0.5 mm residual dentin thickness, and 2-step curing or ramp curing techniques should be considered for curing protocols.

3. Fabrication of provisional resinous crowns

The heat generated from the exothermic reaction of acrylic resin used in fabrication of provisional crowns tends to be higher than that of composite resin.[8] In vital crown preparation cases, the temperature rise during fabrication of provisional resinous crowns can result in pulp damage as well as physical damage such as the removal of tooth substance.[26] The resulting measurement of intrapulpal temperature rise when fabricating provision crowns using acrylic resin was approximately 12.3℃, which exceeds the threshold temperature increase of 5.5℃.[8]

To reduce the damaging effect from the polymerization exothermia of acrylic resin, the use of an air-water spray as a cooling technique, or removal of the temporary crown before the initial polymerization has been proposed.[27] Some clinicians use a putty matrix obtained by a preoperative impression or diagnosis model, explaining that this would act as a heat sink by dissipating exothermic heat.[9] Castelnuovo *et al*. reported a significantly lower temperature increase when comparing a case using a putty matrix and a case that did not. The temperature rise without such a matrix was 12.3℃ and was 7.8℃ with putty matrix.[8] However, this can also cause pulp damage, as this is higher than the threshold temperature increase of 5.5℃, and considering that a higher temperature rise is expected

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when using more amount of acrylic resin, it could be more dangerous when fabricating multiple-unit temporary bridges.[8] Accordingly, it was suggested that putting a putty matrix in a 4℃ refrigerator for approximately 30 minutes decreased the temperature rise to 0℃, whereas when the putty matrix is used at room temperature, the internal temperature rise was approximately 3.4 - 5.5℃.[9] Undoubtedly the refrigeration of the putty matrix is a method that will take a lot of time, but this method can be considered for a vital crown case with in order to reduce pulp damage and post-operative hypersensitivity.

4. Thermoplasticized root canal obturation

The complete, homogeneous, 3-dimensional filling of the root canal system is the final goal of root canal obturation. As compared with cold lateral condensation of Gutta-percha (GP), the thermoplasticized GP technique provided better sealing at the apical foramen and for lateral canal.[12] However, the thermoplasticized GP technique involves heat source activation to approximately 160 - 200℃ and injection of heated GP, which can consequently raise the temperature of the root surface and have a potentially damaging effect on the tooth-supporting tissues, such as the periodontal ligament, cementum, and alveolar bone.[28]

Er *et al*. measured the temperature of periodontal ligament during canal obturation using a warm GP technique and finite element analysis. The highest temperature increase was 6.5℃, which was lower than the threshold temperature increase of 10℃ suggested by Eriksson *et al*.[10] However, the residual dentin thickness plays an important role in the temperature rise of the root surface during root canal obturation. According to Zhou *et al*., when a plugger at 200℃ was activated for approximately 3 seconds, the highest temperature increase measured on the periodontal ligament was approximately 9.9℃ in the "dangerous zone" during the filling of the mesiobuccal root canal of the lower molar.[12] When this plugger was activated for approximately 4 seconds, the temperature increase was as high as 11.9℃. Thus, it was proposed that the heat source activation should be limited to 3 seconds, especially during obturation of the dangerous zone.[12]

Lipski measured the root surface temperature of the maxillary central incisors and mandibular central incisors when using GP heated to 160℃. It was reported that with the maxillary central incisors, the root surface temperature increase was approximately 8.5℃, but with mandibular central incisors, which have a very thin residual dentin wall, the root surface temperature increase was as high as 22.1℃.[11] It was observed that there was a higher temperature increase when the heated GP was injected in the middle and coronal third rather than the apical third, because the amount of injected heated GP plays an important role in the temperature rise, and the root surface did not cool down after the first injection.[11]

However, in Gutmann *et al.*'s *in vivo* study on mongrel dogs, when the GP was heated to 160℃ and injected into the root canal, the temperature increase of the alveolar bone surface was approximately 1.1℃, which is much lower than the results seen in *in vitro* studies.[28] This was probably because the alveolar bone surface was measured instead of the temperature of the root surface or the periodontal ligament and because of the thermal dissipation effect provided by sufficient blood flow of the tooth-supporting tissues.[11] Molywdas *et al*. carried out histological observation of the periodontal tissues after warm (160℃) GP filling in two beagle dogs and noted inflammation around the apical foramen and collagen fiber destruction.[29] However, such an inflammatory reaction was localized to the apical area and was temporary, and the alveolar bone, root surface, and periodontal ligament appeared histologically normal.[29]

Judging from previous study results, most thermal damage to tooth-supporting tissue from thermoplasticized canal obturation seems to be localized and temporary, which might result in slight symptoms among patients. Even though lower temperature increases are observed in clinical situations, there is a need to limit the heat source activation time to 3 seconds and limit the amount of heated GP injection occurring at once, especially in dangerous zones such as the lower central incisors and mesial root canal of the lower molars.

5. Use of ultrasonics in root canal therapy

Ultrasonic devices used in dentistry have frequencies of approximately 20 - 50 kHz, and the synergistic combination of physical, chemical, and biological action is created through the vibration energy developed by the Cavitron generator.[30] With its mode of action, the ultrasonic device is utilized for endodontic treatment such as canal irrigation, post or separated file removal, or retro-preparation during apico-surgery. The advantages of using ultrasonic devices in endodontic procedures include that the irrigation efficacy can be increased and postoperative discomfort minimized while removing the dentin.[30] However, because of the characteristics of vibration energy, the heat generated from friction between dentin or post and ultrasonic tips is dangerous enough to damage tooth-supporting tissues; hence, many studies have been conducted on these issues.[31]

Comparing the intrapulpal temperature rise during tooth preparation using an ultrasonic device with that of a high-speed handpiece and a laser, the temperature rise was approximately 3℃, which was lower than the threshold temperature, but showed a significantly higher value than high-speed handpiece and laser.[32] These results suggest that ultrasonic devices in retro-preparation should be used with a sufficient quantity of water spray.[32]

The irrigating solution may also become hot due to the friction between the oscillating file and the dentin wall, when using ultrasonic devices in canal irrigation.[33] But in this case, the temperature rise is not directly passed to the root surface as the irrigating solution works as a medium. Because of this buffering role, the temperature rise was reported as approximately 0.4 - 0.8℃, which is not highly concerning.[33]

However, opposed to usage in preparation with irrigation, results are worse using ultrasonic devices in the removal of posts or separated files. Frictional heat between the dentin walls or posts and ultrasonic tips can be easily transferred to the root surface, periodontal ligament, and the alveolar bone through metal posts or files.[13] To make things worse, owing to a limited visual field, sometimes the ultrasonic device is used without water cooling, which is dangerous enough to cause permanent damage to tooth-supporting tissue.[34,35] According to one *in vitro* study comparing the root surface temperatures during post removal using an ultrasonic device, the temperature rise of a water-cooling group was approximately 3.2 - 5.9℃, and the temperature rise of the dry group was 15.2 - 17.6℃.[14] The temperature of the apical part was higher than that of the coronal part, because the post acts as a passage that effectively conducts heat.[14] A study by Dominici *et al*. showed similar results, and when the ultrasonic device is used without water cooling at the maxillary central incisors in post removal within 15 seconds of contact, the temperature rose by 9.5℃ and after 60 seconds, it rose up to 32.2℃.[13] The temperature rise easily exceeds the threshold temperature of 10℃, which means that it is dangerous enough to bring about permanent damage to the alveolar bone and the periodontal ligament. However, this is not only a matter of the presence of water cooling, but also the amount of water cooling affecting the temperature rise created by an ultrasonic device.[36] One study compared the temperature rise of mandibular central incisors during post removal using an ultrasonic device under 40 mL/min water cooling and 20 mL/min water cooling. With the 40 mL/min water-cooling group, there was an approximately 7.7℃ temperature rise, but with the 20 mL/min water cooling group, there was a temperature rise of 15.3℃.[36]

Apart from this, post type, length of exposed post, cement type, type of ultrasonic device, ultrasonic power setting, type of ultrasonic tip, residual dentin thickness, and canal configuration may affect the temperature rise during post or file removal by using an ultrasonic device.[14] Out of these, the ultrasonic power setting, tip type, residual dentin thickness, and presence of water cooling play more important roles.[15] It is commonly expected that the temperature rise is higher with metal post removal than with ceramic post removal, but when the two types of posts are removed with air cooling for 30 minutes, the ceramic posts had a temperature rise of 4.7 - 40.4℃, and the stainless steel post group showed a temperature rise of 11.2 - 31.9℃; however, there were no statistically significant differences between two types of posts.[15] The temperature increase can vary depending on the type of ultrasonic device because the mode of action differs between the magnetostrictive system and the piezoelectric system. It was reported that the latter system generates more heat than the former during post removal.[37] Madarati *et al*. measured the temperature rise of the root surface during file removal, depending on the type of the ultrasonic tip, power setting, and contact time. It was found that the smaller the tip, the higher the power, and the longer the contact time, the higher the temperature increase.[38] Therefore, it is important to use ultrasonic devices with sufficient quantity of water cooling at the lowest possible power and with the smallest possible tip during post or file removal.[38]

From previous *in vitro* study results, it can be easily assumed that permanent damage to the alveolar bone and the periodontal ligament can be caused if one tries to remove posts using ultrasonic devices without a sufficient quantity of water sprays, and with high power. Although there are few case reports about thermal damage from other dental procedures, there are some case reports involving thermal damage on the periodontal structure from post removal using an ultrasonic device. Walters and Rawal reported an extreme complication that occurred during post removal using an ultrasonic device.[35] Necrosis of alveolar bone and the periodontal ligament in the upper anterior region was observed due to thermal damage, and there was an inflammatory reaction in the adjacent nasal cavity, which resulted in the loss of all upper incisors.[35] Gluskin *et al*., also reported three extreme complications after use of an ultrasonic device for post removal at the maxillary central incisors.[34] Overheating of an upper central incisor caused necrosis of the alveolar bone and soft tissue, which necessitated extraction of all upper incisors.[34] With such cases of the careless use of ultrasonic devices, the damage of periodontal tissue can be very serious. The author suggested some clinical guidelines with regard to post removal using ultrasonic device in order to minimize thermal damage. One should take a break for at least 2 minutes for every 10 min of ultrasonic-device use in post removal, one should use ultrasonic systems in which sufficient amount of water can reach the working end, and one should check the post temperature at 1 - 2 minutes intervals.[34]

Conclusions

It is quite clear that various dental procedures produce temperature increases of pulp and supporting tissue from both *in vitro* and *in vivo* studies; whereas, the amount of

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heat produced varies from case to case. Among several factors affecting temperature increase, residual dentin thickness is most important, because dentin has low thermal conductivity and acts as a protective layer from thermal irritation. Therefore, care must be taken not to damage pulp or tooth-supporting tissue when the remaining dentin thickness is less than 1 mm.

Because low intrapulpal temperature increases are expected because of heat dissipation by pulpal, periodontal, and osseous circulation in the clinical situation, there are few reports of thermal damage from restorative and endodontic procedures. Nevertheless, clinicians should be aware of the potential thermal hazard to the pulp and supporting tissue that might result from routine clinical procedures. Therefore, clinical guidelines are summarized below.

1. Tooth preparation: Sufficient water cooling is necessary, and if dry cutting is used, one must use it with light pressure and limit the bur-contact time to less than 20 seconds at a time.
2. Light curing of composite resin: A 1 - 2 mm thick insulation layer of glass ionomer in deep cavities with residual dentin thickness of 0.5 mm, and 2-step curing or ramp curing are recommended for complete polymerization and less heat generation.
3. Fabrication of provisional crowns: In vital crown preparation, air-water spray must be used as a cooling technique. One can also use the putty matrix as a heat sink, and depending on the situation, the putty matrix can be refrigerated.
4. Thermoplasiticized root canal obturation: The heat source activation must be limited to 3 seconds, and efforts must be made to limit the amount of heated GP injected at one time, especially in dangerous zones where the dentin wall is very thin, such as the mandibular incisors and mesial canal of the lower molars.
5. Use of ultrasonic devices in post or file removal: One must use the smallest ultrasonic tips for the lowest power, together with at least 40 mL/min of water cooling. The tip-contact time must be limited to 60 seconds at a time.

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