Thermal Effects Caused by Different Methods of Cavity Preparation

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Abstract: The aim of this literature review is to elucidate the thermal damage inflicted on dental tissue by the various methods of cavity preparation.

The heat generated by rotating instruments depends on factors such as size and type of burs, contact intermittence, torque, instrument abrasiveness, load, and the amount of tissue removed. Because these instruments present disadvantages for cavity preparation, new techniques have been sought as alternatives for dental hard tissue removal. The earliest lasers used in dentistry were the ruby and CO_2 lasers, which generate heat above the pulp tissue. Since then, several studies have been conducted using laser systems: Nd:YAG, excimer lasers and erbium lasers. The Er:YAG laser demonstrated the best efficacy with less heat generation compared to the other lasers and showed similar results to those achieved with high-speed handpieces. The Er:YAG laser is an alternative method for cavity preparation and caries removal procedures without excessive thermal side effects.

Keywords: laser, temperature, high-speed, Er:YAG, cavity preparation, hard tissue.

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Tooth preparation is potentially one of the most hazardous procedures for dental pulp, regardless of the equipment used, because if uncontrolled, the heat generated during the procedure can damage the tissue irreparably,[1-5] causing pain and discomfort for the patient.

Heat during cavity preparation procedures is a major source of trauma. Various alterations may result from heat increase, such as postoperative sensitivity, the development of reparative dentin tissue, tissue burning, and pulp necrosis. The extension and degree of tissue damage depends on both the magnitude and the duration of heating in the substrate.[6] One study[4] reported that temperature increases of more than 5.5°C and 11.1°C in the dental pulp could promote irreversible inflammation in 15% and 60%, of the tested subjects, respectively, and concluded that increases of 11°C invariably destroy the pulp tissue. On the other hand, histological results from several studies suggest that average increases of 11.2°C do not damage the pulp, since no signs of inflammation and no reparative processes were detected in the test samples within 68 to 91 days after treatment.[7] It also suggests that the pulp damage is not caused by vibrations or heat during clinical drilling, but that it is more likely due to the severance of odontoblastic processes[8] or an inflammatory process caused by caries lesion development and aggravated by the restoration procedures.[9]

The temperature rise in dentin during cutting may be more crucial than the one caused by deep cuts in enamel, since the pulp tissue, which may suffer biological damage and thermal diffusion, is adjacent to dentin.[4] Thus it is advised that 2 mm of dentin be left between the pulp and the cavity floor to ensure adequate insulation of the pulp tissue from potentially traumatic operative techniques.[10]

Over the years, many techniques have been attempted for painless, less unpleasant cavity preparation and caries removal, without the need of local anesthetics.[11,12] Among these technique, lasers were studied as an alternative method for tooth preparation because they produce no mechanical vibration and may be better accepted by the patients.[13-16] Many lasers have been studied in dentistry since the 1960s,[17,18] including CO_2, Nd:YAG, Ho:YAG, and ArF lasers, but the thermal side effects posed a major problem. However, the Er:YAG laser demonstrates not only superior performance regarding the ablation rate during tooth preparation,[19] but also, due to its wavelength (2.94 µm),[20] it is able to act on the water in the tissues and in this way generates less heat during cavity preparation. Furthermore, it causes less alteration in the irradiated tissues.[21]

The laser acts differently on different structures because of the difference in the composition of substrates. Dental enamel consists mainly of inorganic material with less water content than dentin and cementum, which contain a high percentage of organic material and water.[22] Several studies demonstrated that the ΔT for cavity preparation in enamel was higher than the ΔT for preparation in cementum, which can be explained by the different structures of the tissue.[23] Another important factor that should be analyzed is the thermal conductivity of the material relative to the laser, taking into account the laser mode, wavelength, and other laser parameters. The thermoconductivity of dentin is much lower (K: 5.69×10^3 W/cm°C) than that of enamel (K: 9.34×10^3W/cm°C),[24] which is a factor that also influences substrate response.

In view of the different instruments for carious tissue removal and cavity preparation, the aim of this literature review was to elucidate the thermal damage caused to dental tissues by the various methods of cavity preparation.

ROTATING INSTRUMENTS

The rotating instruments, which may be used in low- and high-speed handpieces, are powered by compressed air which provides an approximately constant power to drive the bur. When the bur meets the tooth resistance, an increase of bur pressure occurs and there is a decrease in the rate of rotation. In this case, part of the energy supplied by the air compressor is being used to overcome the resistance caused by the tooth. This energy at the interface between the bur and the tooth is potentially available for material removal as well as heat generation in the tooth.[25] The high-load techniques produce greater heat generation in cavity preparation than the low-load techniques.[5]

The heat generated by rotating instruments depends on such factors as the size and type of burs, contact intermittence, torque, instrument abrasiveness, load, and the amount of tissue removed.[1,5,26-30]

The handpieces should be water cooled, especially the high-speed handpieces, for many studies show the water spray to be an important means of tissue cooling during cavity preparation.[1,5,30-34] The literature shows that in dry-cut cavities, the mean pulp temperature increase is greater than 5.5°C,[5,26] and is at least 5°C higher than with water spray;[35] this may cause irreversible inflammation.[4] Therefore, even for short time intervals, dry cutting can pose a significant risk in preparations near the pulp tissue.[36] The coolant water temperature should not exceed 35°C.[27] The water flow has a direct effect on thermal damage, and optimum coolant flow rates may minimize the damage to the dental pulp during restorative procedures.[4,30,32,34,37] Öztürk et al[38] concluded that cavity preparation using a high-speed handpiece without water cooling, as well as a low water cooling flow rate (15 ml/min) with a high load, increased the temperature by more than the critical 5.5°C; with copious water cooling (40 ml/min), it never exceeded the critical value.[38]

Dry cutting in enamel can induce sufficiently high thermal stresses to fracture the enamel and produce cracks in the cavity wall that may eventually contribute to marginal failure.[36] In dentin, it was observed that the cavity preparation without water caused a temperature increase in the substrate. Creation of smear layers by bur cutting reduced dentin permeability to levels that were only 1% to 3% of the maximum permeability value.[39]

The other factor that influences the thermal effects on dental tissue is the type of bur. Diamond burs produce a greater increase in temperature compared with tungsten carbide burs.[40,41] This may be attributed to the greater contact between the diamond grit and the enamel, thereby raising frictional heat more than do the blades of a tungsten bur.[42] Brown et al[36] showed that the rate of energy deposition is about the same for enamel and dentin, with the diamond stones depositing slightly more energy than the carbide crosscut stones.[36,40]

There are two important sources of energy in the cutting process: the clinician and the handpiece. There were significant differences in thermal changes among different handpieces, cutting techniques, and applied air pressure.[36,38] Hatton et al[43] determined that the pressure applied during tooth preparation and the duration of contact of the bur with the tooth has a direct influence on the temperature of the pulp. Those authors established that doubling the rotating speed of the bur and/or pressure applied on the handpiece produced a 50% temperature increase on the tooth. The operator with a lighter touch exerts less energy on the tooth.[43] Brown et al also indicated that low attack frequency with light pressure applied to the bur and low air pressure to the handpiece results in the lowest rate of energy deposition, but also in the lowest rate of material removal.[36] In spite of this, Watson et al found no adverse effects related to the use of high torque/high-speed handpieces as compared with air turbine handpieces. The added benefit of a 1:5 speed increase in the handpiece is not compromised by increased tooth damage.[41]

LASERS

Because the rotating instruments present some disadvantages in cavity preparation such as noise, vibration, stress, and pain, new techniques, especially lasers, have been developed as potential alternatives for dental hard tissue removal. Lasers present different properties and characteristics, and their effect on the tissue depends on their wavelength and tissue absorption. When laser power strikes a tissue surface, it can be reflected, transmitted, or absorbed. Most of the changes in the tissue are caused by the absorbed power, which is a thermal process.

The earliest lasers used in dentistry were the ruby[44] and CO_2 lasers,[45] which generate heat above the pulp tissue tolerance level when used on mineralized tissues.[1,47,48] Since then, several studies have been conducted with other laser systems: Nd:YAG,[49,58] excimer – in particular the ArF – laser,[50,51] Er: YAG,[21] and Ho:YAG laser.[52]

CO_2 and Nd:YAG

CO_2 and Nd:YAG were the first lasers used in dentistry, although major problems resulted from the thermal side effects, leading to irreversible pulp damage.[48,53-55]

The interaction mode of these lasers with the tissues is photothermal. Because of this, the hard tissues surrounding the irradiation site may be altered by the conversion of the absorbed laser power into heat,[57] which is the greatest limitation to their use in clinical practice.

The CO_2 laser irradiation wavelength varies from 9 to 11 μm, and thermal effects caused by incident lasers pulses with irradiation intensities as low as 0.5 J/cm^2 at 9.3- and 9.6-μm wavelengths with a duration of 5 to 8 μs were sufficient to induce chemical and morphological changes in dentin.[58] This wavelength presents a strong absorption band in tooth enamel, producing cracks in the substrate and a glazed appearance on the surface of the tooth.[60,61] For the Nd:YAG laser, which has a 1.064-μm wavelength, it was observed that the irradiated substrate present misted, recrystallized, and glazed surfaces.[62]

Several studies[2,82,86] reported that the CO_2 laser produced a temperature rise of 37.46°C, and the Nd:YAG laser an increase of 28.70°C, thereby both causing irreversible pulp damage; other sources have also found CO_2 to yield the highest increases.[47]

Er:YAG

In Er:YAG ablation, although regarded as a hydrokinetic system, water vaporization occurs within the tissue, leading to microexplosive loss of tissue.[21] Moreover, all three major constituents of dental hard tissues – hydroxyapatite, collagen, and water – have absorption peaks in the 2.90-μm region,[14,63] coincident with the Er:YAG laser wavelength (2.94 μm). Thus, it should ablate hard tissues with greater effectiveness and efficiency.[53]

Because of its mechanical ablation process via microexplosions, the Er:YAG laser apparently results in safer tooth preparation, together with its improved performance in terms of the ablation rate.[13,14,20,21,64,65] Some authors, however, found that it generates heat,[19,31,65,67-69] and they reported some modified structures probably caused by the tissue irradiation.

Some histological studies have shown that pulp response to Er:YAG laser irradiation is minimal, reversible, and similar to that of a high-speed handpiece.[14,63,71] Light microscopy revealed no histological changes compared to non-manipulated samples. However, analysis with the electron microscope demonstrated disruption of nerve terminals in the dentinal tubules, degeneration of nerve terminals between the odontoblasts, and disruption of the myelin sheath in the pulp core.[72]

Takizawa, in an in vivo experiment in human teeth, confirmed by pulp histology the safety of Er:YAG laser during cavity preparation of teeth.[73] Later, Pelagalli et al[74] also demonstrated that the Er:YAG laser, operating at 80 mJ and 5 to 10 Hz and at 120 mJ and 5 to 10 Hz, is safe and effective for cavity preparation, and showed no significant histological differences compared to the bur-prepared teeth.[74] Dostalova et al[75] observed no inflammatory reaction in the pulp or burning reaction; the vascularity of the pulp was also considered normal and the odontoblasts were of the usual spindle-like or star-like shape.

The studies that evaluated temperature increases with the use of Er:YAG laser present great differences with respect to power settings, frequency, size, and depth of the preparations.[13,20,64,67,69,70] However, there is consensus on the importance of using water cooling for laser cavity preparations.[13,48,68,70,76] Some studies have shown that the use of Er:YAG laser without cooling is impractical, since minimal enamel was removed and high temperature increases were recorded.[20,31,77] Armengol et al[57] showed that the use of water spray was essential and that this is at least one aspect where the Er:YAG laser could replace rotating instruments for safe removal of dental hard tissues. The bur-prepared samples without water cooling presented a temperature increase peak of 24.7°C, contrasting with the dentin ablation performed by Er:YAG laser or a rotating instrument plus spray, which induced temperature increases of < 5°C.[57,76]

The quantity of water spray must be adjusted in conjunction with other irradiation parameters. If the water flow is not high enough, a significant dentin charring occurs, crystallized debris adhere to crater walls, and the temperature increases exceed 15°C.[31] Flow rates as low as 4.5 ml/min contribute significantly to cooling, limiting temperature rises to < 3°C, with a slight decrease in the ablation rate.[31] For effective and safe dentin removal, Hibst and Keller[79,80] advocated a water flow of 1 to 2 ml/min for a low pulse repetition rate (2 to 4 Hz) and power ranging from 150 to 250 mJ.

Due to the structural and compositional differences in the dental hard tissues, different behavior was observed among the laser-irradiated substrates. On enamel, there is a significant influence of pulse rate but not pulse power, while in the cementum, there is a significant effect of pulse power but not pulse rate.[23]

The pulse mode also influences heat generation. The very short pulse mode increases temperature less than does the short pulse mode.[79]

Caries removal by Er:YAG laser is also very effective, because of the demineralization of the tissue and its high water content. Moreover, it promotes low temperature elevations in the pulp chamber as compared with cavity preparation.[23]

Er,Cr:YSGG

Some studies have shown that the Er,Cr:YSGG laser is able to perform straight, clean cuts through hard dental tissues.[82,83] The mechanism of cutting, unlike that of other laser systems, requires the presence of an air/water vapor that bathes the surface of the sapphire crystal as it delivers the laser power to the target. This device generates precise hard tissue cuts by the interaction of laser power with the above-mentioned water at the tissue interface.[82-85] A study by Rizoiu et al[86] documented that there are no apparent adverse thermal effects of Er;Cr:YSGG cavity preparation on the pulp, and even that a 2° to 3°C drop in temperature occurred, which was considered to be secondary to the cooling effects of the water vapor.[86] In in vivo histopathological studies, the findings indicate no evidence of pulp changes over time for deep, non-exposed cavity preparations.[71,83]

Excimer Lasers

Excimer lasers differ from other lasers in three ways: they emit radiation in the UV band, their energy photons are capable of directly breaking the molecular bond, and their pulses are very short (15 ns), which prevents a large accumulation of heat in the irradiated areas.[35] The ArF excimer laser (193 nm) has an energy of 6.4 eV per photon.[50,51,55] In excimer lasers, with decreasing wavelengths (308 nm > 248 nm > 193 nm), the thermal side effects decreased, whereas the ablation effects increased.[50,55]

The ArF laser produced a 1.05°C temperature rise, but compared with other lasers, it produced the smallest cavity depths.[35]

DISCUSSION

An important factor in tooth tissue preparation is to maintain the temperature increase below 5°C in the pulp chamber.[87] Temperature increases of over 6°C can be associated with complete destruction of pulp.[4]

In this literature review, the Er:YAG laser demonstrated the highest efficacy with less heat generation than the other lasers. Some studies showed similar temperature increases to the high-speed handpiece.[14,63,71] There are some limitations yet for its use, because not enough studies have been conducted to make recommendations on the optimal parameters for this application.

It is a fact that the temperatures are higher for enamel ablation than for dentin removal,[88] but the distance to the pulp cavity is less in dentin. From this standpoint, pulp vitality is in greater danger from the overheating of dentin.

The parameters used in the experiments are also very important, and several studies have shown that limited application of Er:YAG laser power below 500 mJ, repetition rate below 8 Hz,[89] and use of water spray can protect the dental tissues.[67,68]

The temperature rise in the pulp during in vivo laser cavity preparations will be lower than in hard tissues because of the nature of the pulp tissue itself, which includes blood circulation causing heat dissipation, and the higher water content of the vital tooth structures.[82]

However, further research, mainly clinical studies, is required to validate the Er:YAG laser as a caries removal and cavity preparation method without promoting significant alterations to the pulp and adjacent tissues.

CONCLUSION

Among lasers, the Er:YAG laser is an alternative method for cavity preparation and caries removal without excessive thermal side effects. However, due to the cost of the equipment and current paucity of clinical studies, its use is still limited for professional practice.

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