Pulp Capping – from Conventional to Laser-assisted Therapy (I)

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Abstract: This article presents an overview of the current knowledge in conventional and laser-assisted pulp capping, based on different research records. The pulp capping technique is mainly based on the healing ability of pulp tissue. The most obvious reparatory response of the pulp lesion is the formation of tertiary dentin. Moreover, this paper outlines the use of different laser wavelengths in order to improve the outcomes of pulp capping. Laser therapy has proven its effectiveness in pulp capping and vital pulpotomy by its capacity to stimulate the repair dentin formation by the pulp tissue, its ability to decontaminate irradiated surfaces, as well as its pain reducing effect. Three clinical cases are also presented.

Keywords: pulp capping, laser, conventional treatment, tertiary dentin.

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A pulpal exposure is defined by MeSH (Index Medicus: Medical Subject Headings) as "the result of pathological changes in the hard tissues of the tooth, caused by carious lesions, mechanical or traumatic factors, which render the pulp susceptible to bacterial invasion from the external environment". The definition of pulp capping accepted by MeSH is "placement of a protective agent on exposed pulp tissue (direct pulp capping) or on the remaining dentinal layer above a nearly exposed pulp tissue (indirect pulp capping) with the purpose of tissue regeneration, maintaining of pulp vitality and a normal pulp function."

According to ESE (European Society of Endodontology) 2006, pulp capping represents a procedure in which the exposed dental pulp is covered with a protective dressing or a basic material is applied directly on the exposed area. The official definition of pulp capping approved by the American Association of Endodontics is "a procedure in which a dental material is applied on an exposed or nearly exposed dental pulp, in order to stimulate the formation of irritation dentin in the exposed area".[1]

Direct pulp protection or direct pulp capping is, according to Pereira and Bramante, "treatment of exposed dental pulp with appropriate materials for the preservation of pulp vitality and formation of a mineralized tissue barrier".[2] This idea is also sustained by Stockton, who adds the fact that dental pulp vitality ensures tooth resistance to mastication forces through its nutritional and repairing qualities.[3] According to Swift et al, pulp capping, whether it is direct or indirect, or if it involves total or partial preservation of pulp tissue, represents a method for maintaining tooth vitality.[4]

Vital pulpotomy represents the common therapy for cariously exposed pulps, the main goals being the preservation of radicular pulp vitality, and avoidance of pain and inflammatory reactions.[5]

Seventy to 80 years ago, it was acknowledged for the first time that a pulpal exposure may be the object of a successful treatment. According to Cox, Hermann introduced the concept of calcium hydroxide in 1930 for use as a stimulant for pulpal wound healing;[6,7] the phenomenon spread together with the discovery of calcium hydroxide incorporated in a water-based vehicle as an optimal dressing for the initiation of the reparation process of pulp tissue.[8-11] Since then, the reparatory response of pulp tissue has been considered a favorable result, indicating pulpal healing.[6,12]

Without taking into account the chemical or biological pulpal stimulant used (calcium hydroxide, collagen, fibronectine, TGF and dentin fragments), the feasibility of pulp capping depends on the presence of an endoge-

nous pulp tissue and is, by definition, a treatment designed exclusively for vital dental pulp.[8] The pulp capping technique is mainly based on the healing ability of pulp tissue. Numerous factors influence this process, including age, periodontal conditions and stage of tooth maturation.[13] The topographic location of the exposure is also important, with the existence of pulp tissue coronal to the exposure site not being recommended, considering the necessity of blood supply for tissue survival in this area.[14]

When treatment is successful, pulp capping results in pulpal wound healing and partial dentinal regeneration above the exposed area. This success, mainly observed in young teeth, may not occur in mature teeth, which display a variable and unpredictable prognosis. This fact has been attributed to lack of materials for hermetic sealing of the pulp, but is also due to the clinical impossibility of establishing the extent of the inflammatory process.[8] Successful pulp capping is obtained when the following clinical conditions are met: uninflamed pulp, adequate hemorrhage control, good antibacterial seal and use of a capping material tolerated by the pulp tissue.[4]

Preservation of pulp vitality depends on the degree of pulp cell survival after completion of restorative procedures, as well as on the lesion detection ability of these cells and their reactivity for the initiation of the pulp tissue reparation response.[15]

Murray claims that the results of pulp capping depend on the presence of healthy pulp tissue, asepsis, as well as absence of microbial microinfiltration.[16] Many authors emphasize the importance of the dimension of the exposure site; the pulp capping procedure is recommended in cases where the pulpal lesion area is very small – 1 mm or less – and the patients are young.[6,17]

Some authors consider pulp capping as the first choice of treatment, followed by endodontic treatment according to its outcome.[18,19] Some authors do not recommend pulp capping in cases of carious exposures, and reserve treatment only for teeth with minimal signs of pulpitis.[3,6,20,21]

According to Murray's study,[22] the most influential variables in determining pulpal lesions have been identified as the thickness of the remaining dentin layer, cavity preparation without a cooling system and selection of restorative material for covering the exposure site.

Only a small number of studies have confirmed the success of conventional pulp capping in mature teeth, such as Hoerstedt,[23] who found 90% success 5 years after treatment of teeth in patients aged 10 to 30 years, and Zilberman.[6,24]

The evolution of technology in the field has demonstrated the efficiency of laser equipment for pulp vitality preservation, by qualitative improvement of the working conditions, evidenced by the clinical and biological situation of the treated pulp tissue, mainly by disinfection, hemorrhage control and sealing of dentinal tubules.[25,26]

The most obvious reparatory response of the pulpal lesion is the formation of tertiary dentin matrix. Unlike primary and secondary dentin, which form along the whole pulp-dentin interface, tertiary dentin is secreted by odontoblasts, strictly targeting the affected area. The secretion process of tertiary dentin may be classified as being of reactionary or reparative origin, according to the severity of the initiated response and the conditions in which the new tissue matrix is formed. Usually, reactionary dentin is secreted by pre-existing odontoblasts, and reparatory dentin is secreted by newly differentiated odontoblast-like cells. The secretion of tertiary dentin depends on the pulp capping material, degree of mechanical damage to the pulp, presence of preparation debris at the exposure site, inflammation, and bacterial microleakage. The practician must pay attention to the cavity preparation, as well as to optimal placement of the capping material, which benefits the formation of tertiary dentin.[15]

In 1993, Mejare and Cvek stated that in the case of deep carious lesions, a pulpal exposure should be undertaken, in order to remove 1 to 3 mm of pulp tissue.[27,28] This procedure is closer to a partial pulpotomy than to pulp capping, being effective only in the case of young teeth. The advantages of this method are: reduction of infiltration into the pulp tissue of dentinal debris during preparation, assurance of an intimate contact between the capping agent and the pulp, removal of contaminated superficial pulp tissue.[14]

A series of techniques have been proposed for partial pulpotomy,[29] but the studies are contradictory regarding the most appropriate method for such a situation.[30] Diluted formocresol is presently regarded as the "golden standard" of conventional treatment,[31] but some studies claim its inapplicability, based on its cytotoxicity and mutagenic potential.[32] According to other authors, calcium hydroxide causes internal resorption.[33] Fuks et al used ferric sulphate because of its hemostatic effect.[5] A modern alternative is Er:YAG laser, justified by its hemostatic, antimicrobial, and cell-stimulating properties,[34-36] with insignificant tissue alterations observed at pulp level by Jayawardena.[37]

PULP CAPPING AND VITAL PULPOTOMY – CONVENTIONAL TREATMENT

Calcium Hydroxide

Calcium hydroxide is the most widely used pulp capping agent. The calcium hydroxide pulp capping method has demonstrated its efficiency over long periods of time.[15] The healing and repairing of accidentally or traumatically exposed pulp tissue, after capping with calcium hydroxide, has had great success according to studies conducted by numerous researchers.[6,28,38-40] Because of its high pH, calcium hydroxide has optimal antibacterial activity and encourages tissue repair by promoting tertiary dentin secretion. The negative characteristic of calcium hydroxide is its physical instability, allowing the migration of particles into the pulp tissue, causing inflammation and thereby being a possible factor of necrosis.

Many authors have attributed to calcium hydroxide the capacity to induce hard tissue neoformation, but this concept was contested by Cox in 1972, by demonstrating pulpal healing and dentinal barrier formation in the absence of calcium ions. He obtained favorable results in the presence of a large spectrum of low pH agents, like silicate and zinc phosphate cements. Moreover, Brännström demonstrated the inherent healing capacity of dental pulp in absence of bacterial inflammation.[6,7,41]

Animal studies

Kitasako et al[42] were interested in evaluating the location, arrangement and possible function of odontoblastic collagen fibers, in association with the formation of hard tissue bridges induced by calcium hydroxide, in pulp capping with self-setting calcium hydroxide in healthy primates (Macaca fuscata), in the absence of dental or periodontal pathology. Following histopathological and electron-microscopic examination, the importance of interodontoblastic collagen fibers in inducing and sustaining the dentinogenetic matrix was emphasized; these fibers participate in the guidance of preodontoblastic cells in migration, adhesion and arrangement, as well as in the formation of dentinal bridges. The authors consider that these fibers may provide biological and mechanical support, connecting central pulpal fibers and newly formed odontoblastic cells.[42]

In comparative histomorphological study conducted by Mestrener and Holland on the influence of chronologic age of dogs on the pulp healing process after capping with a dentinal adhesive system (All-Bond 2) and calcium hydroxide, the superiority of the latter was proven, both with respect to the age parameter and to the presence and thickness of the dentinal barrier.[43]

Human studies

Pulp capping

Taking into consideration that calcium hydroxide is the most used pulp capping agent, regarded as the "golden standard" in pulp vitality preservation, the majority of articles in the field present a variey of treatment methods involving this material. Calcium hydroxide is used as a pulp capping agent in the positive control group as well as in combination with other materials and methods.

Vital pulpotomy

In 2006, Parirokh and Kakoei published an observation study conducted over an 11-year period, illustrating the success of vital pulpotomy undertaken with calcium hydroxide and cavity filling with glass-ionomer cement, in immature mandibular incisors of a patient exposed to accidental trauma. The authors proved that vital pulpotomy must not necessarily involve complete endodontic treatment, with the possibilty of preserving radicular pulp vitality.[44]

Dentinal Adhesive Systems

Traditionally, calcium hydroxide has been used as a first-choice material for direct pulp capping. Many dentinal adhesive materials have been proposed to replace calcium hydroxide, but study results are contradictory.[15] In 1987 with the help of histological evidence, Cox was the first to demonstrate pulp healing and dentinal barrier formation after capping with an autopolymerizing dentinal adhesive system.[45]

Animal studies

Based on histomorphological results obtained for young and adult dental canine pulps, dentinal adhesive systems have proven to be inferior compared to calcium hydroxide, with far thinner dentinal barriers and the presence of inflammatory reaction.[43] In the case of mature pulp, the cell population is significantly reduced, apparently affecting the cells' capacity to generate a reparatory response. The unsatisfactory results obtained for the dentinal adhesive system are due to its cytotoxicity,[46] as supported by many other studies, observing the interruption of dentinogenic activity of pulp cells.[42,47-49] Accordingly, Kitasako emphasizes the importance of adopting an optimal protocol for place-

ment of the dentinal adhesive system, in order to reduce the penetration of monomers with cytotoxic potential into the pulp tissue.[46] Also, many authors underline the importance of the sealing ability of the material used for cavity filling.[50,51] From this point of view, the success of the study conducted by Mestrener and Holland may also be attributed to the glass-ionomer cement used for cavity filling, at the same time explaining the less favorable results obtained by similar studies in which zinc oxide eugenol cement was used for temporary cavity filling. Regarding the sealing ability of zinc oxide eugenol cement, other studies have shown that the obtained results for adult dental pulps were far better than those obtained for young pulps, due to the reduced thickness of the dentinal wall to be sealed in young teeth.[52]

Hafez et al conducted a study on primates in 2001, comparing the efficiency of 2 dentinal adhesive systems with the biological effect of 3% NaOCl as an agent for hemorrhage control and stimulation of odontoblastic reparatory function. Ninety-seven days after treatment, the applicability of NaOCl 3% in reorganizing pulp tissue was evaluated, observing the presence of a dentinal barrier in 86% of the total specimens treated this way.[53]

Kitasako observed there was a problem regarding the molecular migration in the case of dentinal adhesive systems, similar to that of calcium hydroxide.[46]

Tziafas et al[54] evaluated the effects of two self-etching and self-bonding dentinal adhesive systems containing 12-methacryloyloxidodecylpyridinbromide (MDPB) monomer on the repair capacity of the pulp-dentin complex after direct and indirect capping of infected dental cavities in canine subjects. According to the authors, the absence of inflammatory cell response proved optimal biocompatibility of MDPB, the stimulation of tertiary dentinogenesis being attributed to this antibacterial agent. Nevertheless, for direct pulp capping, tertiary dentin was only present in the group treated with calcium hydroxide, and was absent in the groups treated with the dentinal adhesive system. Other contradictory studies proved that adhesive systems block the dentinogenic activity potential of pulp cells.[54]

Some authors discuss the future development of dentinal adhesive systems; especially by incorporating bioactive molecules in order to mediate pulpal reparatory response,[54] including desensitizing and antibacterial agents.[55]

Human studies

Attempting to efficiently exploit the quality of the two materials, Heitmann et al studied the efficacy of the combined therapy of direct pulp capping with calcium hydroxide and cavity filling with a composite resin. The following disadvantages were observed: poor mechanical properties of calcium hydroxide, quality decrease and dissolution of calcium hydroxide through phosphoric acid etching, inhibition or influencing of the composite resin polymerization process by calcium hydroxide due to the infiltration of the adhesive agent, the space occupied by calcium hydroxide being required for dentinal sealing. The potential advantages of pulp capping with a dentinal adhesive and a composite resin include an improved sealing of the peripheral area of the exposure site in order to prevent reinfection and avoid the risks of undertaking a second operative procedure; in this case, more thorough investigations are necessary.[52] Nevertheless, there are some data showing that the resin-based dentinal adhesives are susceptible to in vivo deterioration.

Because bacterial microinfiltration is one of the main causes of pulp inflammation and therefore of pulp capping failure, comparative studies have been conducted in order to determine the sealing ability of composite resins compared to calcium hydroxide in direct pulp capping, but without detecting major differences.[15]

According to Olsson's study of the literature regarding pulp capping with dentinal adhesive systems, few cases were found with evidence of newly formed tissue, suggesting a cytotoxic effect of these materials on the pulp tissue. The less favorable results of human studies were in contradiction to the good results obtained in animal studies.[56]

On the other hand, based on a comparative review regarding the applicability of dentinal adhesives in the treatment of pulpal exposures, Schuurs et al observed that these materials are potentially competitive. Nevertheless, even if the cytotoxicity of these materials and temperature rise during polymerization are no significant disadvantages, the incidence of allergic reactions, sensitization, and sealing ability over long periods of time are factors which may threaten the viability of adhesive systems in the future.[57]

Hoerstedt et al adhere to the opinion of many authors by affirming the insuitability of dentinal adhesive systems for treating pulpal exposures, stating that nowadays calcium hydroxide is the safest material for direct pulp capping.[23,52]

MTYA1-Ca represents a new type of dentinal adhesive system, based on resin and 10% calcium hydroxide. According to comparative in vitro testing of the material in 1999, it presents excellent mechanical properties with superior dentinal adhesion compared to calcium hydroxide (Dycal), and, most importantly, the

development of a dentin barrier, which is slow during the initial observation stages (30 days), but with a development similar to Dycal at the final stage of the study (90 days). The relative cytotoxicity of the material is attributed to the difference of pH and insufficient dilution in vitro. In vivo, this dilution may occur immediately or gradually through the contact of MTYA-Ca with pulp tissue fluids, which may reduce the toxic effect.[58]

MTA (Mineral Trioxide Aggregate)

The most recently used material for pulp capping is MTA, whose biocompatibility is indicated by many studies.[59] MTA seems to be able to stimulate the formation of the dentin barrier at the site of pulpal exposure.[59, 60] To date, the biological mechanism through which MTA induces dentinogenesis is unknown.[61]

Pulp capping with MTA reduces the inflammation, hyperemia, and necrosis levels; it also creates thicker dentin bridges. The odontoblastic cell layer is maintained and proliferates more often than in the cases treated with calcium hydroxide. Apart from pulp capping, MTA is recommended for the repair of dental perforations, filling of immature dental roots, and for apical root obturation.[60]

As MTA is a hydraulic cement with a setting period of approximately 4 h, retention problems may occur in clinical situations. Its fixation is a two-stage process, with the initial form a gel. The characteristics of the fixed material depend on the powder:water ratio, the ambient temperature, humidity, pH, and condensation pressure; these features are not thoroughly enough studied to date.[62] Electron probe microanalysis revealed the chemical composition of WMTA (White MTA); it mainly consists of calcium, silicone, and bismuth.[63] The standard testing techniques for Portland cement are not completely applicable to MTA. Because of the difference in the components' percentages, it is necessary to develop a set of MTA-specific standardization criteria, due to the fact that it is neither an endodontic sealer nor a restoration material. The MTA producers offer no information on the values of necessary condensation pressure for the application of MTA, this variable being out of control in most existing studies, and consequently the obtained results are inconsistent. Therefore, Nekoofar et al studied the effect of condensation pressure on surface hardness, microstructure and compressive strength of MTA, and they observed that water molecules have a crucial role in the MTA's fixation process. They also observed that by applying a moderate pressure, MTA's resistance increases due to improved water diffusion and the formation of a homogenous crystalline structure. In contrast, high pressure creates a thin hard surface layer, while the internal structure consists of isles of condensed powder lacking hydration and chemical bond.[62,63] Torabinejad considers that MTA possesses enough compressive strength to allow condensation of amalgam and presents negligible solubility.[64]

Animal studies

According to Pitt Ford,[65] Junn,[66] and Faraco and Holland[67], MTA has been used successfully compared to calcium hydroxide for pulp capping in animals. MTA is superior to calcium hydroxide as far as pulp capping is concerned.[68] Parirokh considers that the main ability of MTA is providing an optimal seal, preventing the communication between pulp tissue and the external environment.

MTA has shown minimal microinfiltration to dye and bacterial testing compared to other restorative materials. MTA was also proven to be a polyvalent material in dentistry. The gray color of the original MTA, GMTA (gray MTA), may produce dental dyschromia, especially obvious in the front teeth.[68] In order to avoid this inconvenience, WMTA was introduced.

Faraco and Holland proved that the two types of MTA have similar behavior, but ingredients used to alter the material's color may have crucial effects on the quality of the material.[66]

In order to evaluate the efficiency of a material used in pulp capping, the factor that triggers the initiation of dentinal barrier formation must be determined, that is, the irritation or tissue healing process. This may be identified by determining the presence or absence of inflammation, necrosis and dentinal wall resorbtion during dentinal barrier formation. Parirokh did not notice any significant differences between GMTA and WMTA during the comparative study he conducted in 2005, and he recommended MTA for treating pulpal exposures without occlusal loading, such as vestibular exposures.[68]

Asgary et al[63] used SEM and EPMA (Electron Probe MicroAnalysis) in order to determine the main morphology and chemical composition of the new dentinal barrier, obtained two weeks after direct pulp capping using WMTA in healthy dogs. The study was successful and neodentinal formation occurred; the initial SEM examination revealed the presence of WMTA in the pulpal chamber and the direct contact between WMTA, the odontoblastic cells' extensions and the newly

formed collagen fibers. The electron probe microanalysis showed the content of oxygen, phosphorus, and calcium of the newly formed dentin, with increased concentrations at the periphery, suggesting the progressive activation of the calcification process from the pulpal exposure's periphery to the center. The authors attribute MTA's ability to induce the new dentinal barrier's formation to its biocompatibility – given the possibility of biological pulp substrate to adhere to the material surface, but also due to MTA's good sealing properties, its ability to trigger cytokine release, and its osteoconductivity.[63]

Many studies support the concept of the MTA's osteoconductivity, contradicting those that provide evidence of its osteoinductivity.[61]

The available data regarding the use of MTA for conservative pulp treatment in dogs revealed good properties and biological results after the histological examination, showing a completely formed dentinal barrier and minimal tunnel flaws,[67] but this is not necessarily applicable in human teeth.[61] The good results obtained for pulp capping with WMTA in animal studies are consistent with the conclusions of previous studies. WMTA's behavior seems to be similar to that of GMTA.[67]

Human studies

Pitt Ford proved that MTA is able to induce dentin barrier formation, but the handling difficulties and the long fixation time may influence its acceptance as a capping agent of the future.[14,65]

In 2007, Nair et al showed that iatrogenic defects created in human pulp tissue and treated with MTA are less likely to be inflammed a week after treatment; they were covered with compact dentinogenic tissue, which grew and matured constantly during the observation period. The same research team has managed to identify for the first time the initial formation of both dentinal tubules and marginal cells of the dentinal bridge for calcium hydroxide (Dycal) and MTA. It is important to note that MTA's success was limited to intact human teeth, without any interference (ie, cavities, bacterial infections, pulpal inflammations). The authors claim that, technically, the application of Dycal was much more difficult than that of MTA.[61]

Patel and Cohenca demonstrated, for the first time ever, that it is possible to maintain the vitality of a carious, immature permanent human tooth with the help of direct pulp capping using MTA, due to its biocompatibility and its good sealing abilities. The preliminary study was based on the concept of the continuous dental maturogenesis, whose physiological functions of radicular development are not limited to the apical segment. The authors emphasized the importance of careful selection of specimens with carious processes proposed for direct pulp capping, because there are currently no methods for assessing the degree of pulpal inflammation before intervention.[70] A long-term evaluation (2 years) of MTA as an agent for direct pulp capping in primary dentition has shown its similar applicability to that of calcium hydroxide; the authors claim that it is necessary to conduct a histological examination in order to identify the microstructural mechanism induced by this material.[71]

Vital pulpotomy

Karabucak et al were successful in preserving the vitality of permanent human teeth which showed traumatic pulpal exposure (fracture) during their maturation period, by using partial pulpotomy (Cvek) and protecting the remaining pulp tissue with GMTA. The authors consider the following factors to be essential for obtaining a good result in vital pulpotomy: the accidentally exposed dental pulp must not be inflamed, combined with the MTA's biocompatibility, good sealing abilities and alkalinity.[72]

Emdogain Gel

Emdogain gel is the commercial name of a product derived from dental enamel matrix (EMD) used to treat periodontal diseases.

Animal studies

Pulp capping studies using this material were carried out on guinea pigs and revealed EMD's potential to induce new hard tissue formation, but few studies exist regarding the applicability of Emdogain gel for human dental pulp. Olsson and Davies studied the effect of Emdogain gel (a derivate of enamel matrix – EMD – in a propylenglycol-based alginate – PGA – excipient) on exposed human dental pulps and recorded the post-operatory symptoms. The authors have noticed that in the group where Emdogain gel was used, the postoperative symptoms were less frequent and the quantity of newly formed tissue was significant, but due to its arrangement along the dentinal walls, it was not an effective dentinal barrier. The authors concluded that Emdogain gel is ineffective in the formula used for creating pulpal protection.[73] In 2001, Nakamura used EMD, in a comparative study Emdogain gel/Dycal, for

treating pulpal exposure of 22 maxillary premolars of miniature pigs. He observed at 2 weeks and then again at 4 weeks after treatment the presence of a newly formed dentinal barrier whose thickness was double compared to the specimens which were treated with calcium hydroxide ($p < 0.001$), which shows EMD's superior ability to sustain reparatory processes.[74]

LASER-ASSISTED PULP CAPPING AND VITAL PULPOTOMY

The technological progress in the field of preserving dental vitality after accidental, traumatic or caries-related pulpal exposure justifies the efficiency of laser equipment. It improves the clinical and biological status of treated pulp tissue, due to its wound conditioning ability through disinfection, dentinal tubule sealing, and hemostatic control.[25,26]

To date, the types of lasers used in pulp treatment procedures are: CO_2, Nd:YAG, Er:YAG, Er,Cr:YSGG, 980 nm GaAlAs diode laser and 810 nm GaAlAs diode laser.

In other respects, Tunér and Hode (cited by Gutknecht) consider that laser therapy can be recommended for pulp capping and pulp amputation of deciduous teeth. Laser therapy appears to stimulate the odontoblast calcium and collagen production, leading to secondary dentin formation.[75,76]

According to Gutknecht et al, pulpotomy is a very common technique in pediatric dentistry, and CO_2 laser is described as very effective, but pulsed Nd:YAG lasers are also applied.[75,76]

The major advantage of CO_2 laser in the field of preserving pulp vitality is its thermal effect; it sterilizes and heals the irradiated area, ensures a close contact between the dental pulp and the capping agent by reducing inflammation and the size of the blood clot, and it may also help to prevent bacterial microinfiltration, which is the key factor in pulp capping failure. Apart from these positive results, Paschoud and Holz attribute to CO_2 laser the ability to directly stimulate the dentinogenesis process.[77]

According to Pescheck and Moritz, CO_2 laser is an easy, safe and fast method for hemostasis, disinfection, and sealing of exposed pulp tissue, especially because it is possible to operate the CO_2 laser in superpulsed mode, thus considerably reducing the thermal effect on the adjacent tissues.[78] Stabholz and Rocca have noticed that it is necessary to decrease dentin permeability in order to ensure good results of indirect pulp capping. The Nd:YAG and CO_2 lasers are capable of reducing dentin permeability, thus they are recommended for conditioning the remaining dentin layer by sealing dentin tubules in indirect pulp capping.[25]

Many studies have revealed that laser radiation accelerates the formation of dental hard tissue by the dental pulp; this fact can be applied in pulp capping and vital pulpotomy.[79]

Er:YAG or Er,Cr:YSGG lasers may be used to perform a whole operative procedure, from caries excavation, coagulation of the exposed pulp, pulpotomy or pulpectomy. It may be useful to consider a treatment concept in which using these lasers is considered as a continuity, from caries removal to disinfection, cleaning, pulp tissue coagulation, and even ablation.[80]

Animal Studies

Numerous animal studies (using rodents, primates, and dogs) – beginning with the study conducted by Melcer on primates (Macaca mulatta) – have shown that CO_2 laser treatment triggers the formation of mineralized dentin without modifying pulp tissue.[25,26,81-84]

The first laser pulpotomy was performed by Shoji et al in 1985; they used CO_2 laser in focused and defocused mode, with power levels of 3, 10, 30, and 60 W, in the dental pulp of dogs. They noticed coagulation necrosis and degeneration of the odontoblastic cell layer, without damaging the radicular pulp tissue.[25,85]

Ebihara et al published a study in 1989, in which they observed the efficacy of Nd:YAG laser, set at 2 W, irradiation time of 2 s, for healing pulp tissue and forming the dentin barrier in dogs, observed at 1, 4, and 12 weeks after treatment.[86]

According to a comparative study conducted by Jukic on dogs, Nd:YAG laser (energy density of 6.3 J/cm^2) and CO_2 laser (energy density of 4 J/cm^2) caused carbonization, necrosis, inflammatory response, edema and bleeding in pulp tissue, with poor dentinal barrier formation.[87]

White noticed that the use of an Nd:YAG laser with the parameters 1 W power, 10 Hz repetition rate, total exposure time of 10 s, does not significantly increase the temperature of the pulp tissue; these parameters represent the upper limit of laser application on pulp tissue.[15,88]

Wilder-Smith and Dang demonstrated the efficacy of CO_2 laser for partial pulpotomy in dogs, regarding teeth with wide exposure and bacterial microinfiltration, through the presence of reparatory dentin and of an intact odontoblastic cell layer.[89,90]

According to many researchers, CO_2 laser 9.6 μm is absorbed by the hydroxyapatite crystals in enamel and dentin, causing tissue ablation, melting and resolidification of tissues,[91] without harming dental pulp in dogs.[92]

In 2003, Manabu et al evaluated (at 3, 30 and 90 days after treatment) the histopathological response of dental pulp in adult primates (Macaca fascicularis), using CO_2 – Opelaser 03S – in focused mode (PHI 0.2 mm) with a series of 15 impulses lasting 0.1 s – and a two-step adhesive system, compared to the effect of calcium hydroxide. Apart from the hyperemia and more intense inflammation shown by the specimens treated with laser and a dentinal adhesive system, during the first two stages of the observation process, when the thickness of the dentinal barrier was measured, 90 days after treatment, the whole laser-assisted group displayed the poorest results.[93]

In a similar study, Suzuki et al examined the healing process of dental pulp in rodents (rats) after direct pulp capping using different experimental adhesive resin systems, combined with CO_2 Opelaser 03S IISP (power 0.5 W, superpulsed mode 1, repeated pulsed mode, with a 10 ms irradiation and 10 ms interval cycle, defocused action range ~20 mm distance to the surface of pulpal exposure and an irradiation period of 3 s, activated air-cooling system). At the end of the observation period (2 weeks after surgery), the specimens exposed to laser radiation showed a very irregular fibrous dentin matrix next to the pulp tissue and no reparatory dentin, while the control group (treated with calcium hydroxide and adhesive resins) showed a consistent layer of reparatory dentin. Nevertheless, it is important to note that all specimens showed an almost normal pulpal morphology. The authors conclude that CO_2 laser is effective in wound control, but a prolonged period is necessary to obtain conclusive results concerning the formation of the dentin barrier.[94]

The studies performed by Tate et al to evaluate the effect of GaAlAs 810-nm semiconductor laser in pulsed mode on animal (rat) odontoblastic cells, using immunohistochemistry with HSP-25 (heat-shock protein) – which characterizes newly differentiated and mature odontoblastic cells – confirmed the results obtained with Nd:YAG laser regarding the stimulation of tertiary dentin and bone-like tissue apposition. The authors demonstrated the usefulness of HSP-25 as a marker of odontoblastic cell behavior during post-traumatic pulpal healing. They also observed the effects of the applied laser parameters (pulsed mode, 180 s total irradiation time, while increasing the irradiation power ranging from 0.5 to 1.5 W and maintaining contact between the laser fiber and the treated surface) on the secretion activity and post-irradiation survival rate of odontoblastic cells. The authors established the conditions necessary for the formation of a certain type of hard tissue: the existence of a remaining odontoblastic cell layer triggers the formation of reaction dentin, while the destruction of the odontoblastic cells is followed by mesenchymal pulp cell migration to the exposure site and their degeneration, which determines the appearance of repair dentin.[95]

While trying to compare pulpal reactions induced by diode laser (Ceralase D-980 nm, Biolitec) and calcium hydroxide in immediate and 24-h postponed pulp capping in macaque monkeys (Macaca fascicularis), Toh et al found that the used laser parameters (power 1 W and 2 W respectively, 1 s exposure time, 600 μm fiber diameter) and postponing pulp capping showed no significant influence on the therapy result. It is important to note that the final results were similar for both groups. The group which was subject to pulp treatment using diode laser developed normally during the entire observation period (90 days), while the control group, which was treated conventionally with calcium hydroxide (Dycal), showed a necrosis peak 30 days after surgery. The difference disappeared at the final evaluation, when all the studied specimens showed relatively normal pulp tissue.[96]

In 2007, Todea tested the stimulation capacity of the pulpal reparatory function in an experimental animal study (40 molars from 20 male Sprague-Daley rats) using a 980-nm laser diode (working parameters: 0.5 to 2 W, on 0.01 s, off 0.01 s, energy 1.30 to 1.80 J, duration of treatment 1.01 to 2.04 s, 30 pulses, 5 exposures/procedure, 1 procedure/tooth). During the histological evaluation, which took place 6 and 12 weeks after surgery, she noticed that the combination between diode laser and calcium hydroxide is a viable therapy method, stimulating reparatory neodentinogenesis, with statistical values of $p < 0.005$. The tooth specimens were divided into 4 groups: groups 1, 2 and 3 were treated using laser with increasing energy levels, while group 4 was treated conventionally with calcium hydroxide; all the exposures were covered with calcium hydroxide and the cavities were filled with glass-ionomer cement. Halfway through the observation period, the presence of a necrotic layer was noticed in the 3rd group (treated using 2 W laser). At the end of the observation period, Hohl cell layers were detected in all the specimens in groups 1, 2, and 4 and in 33% of the specimens in group 3 (Fig 1).[97]

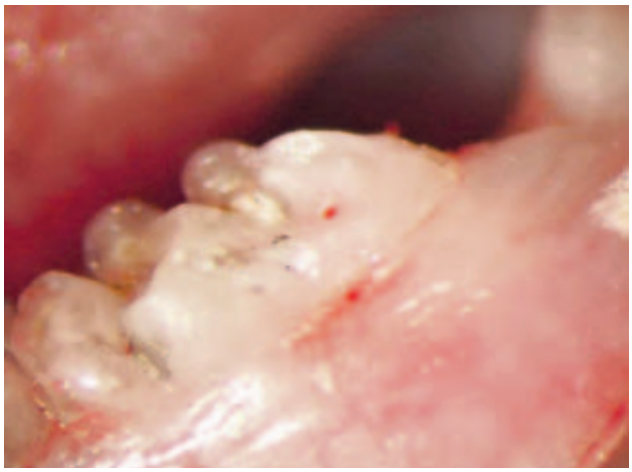

Fig 1a Class I cavities prepared on the buccal surfaces of the first rat molar. Pulpal exposure site.

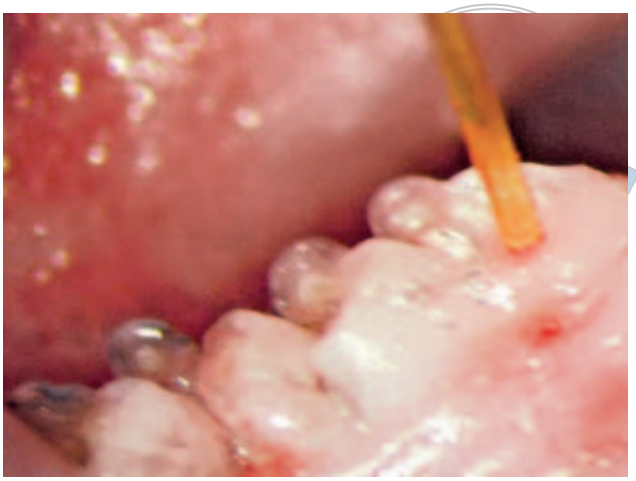

Fig 1b Class I cavities prepared on the buccal surfaces of the first rat molar. Laser-assisted direct pulp capping.

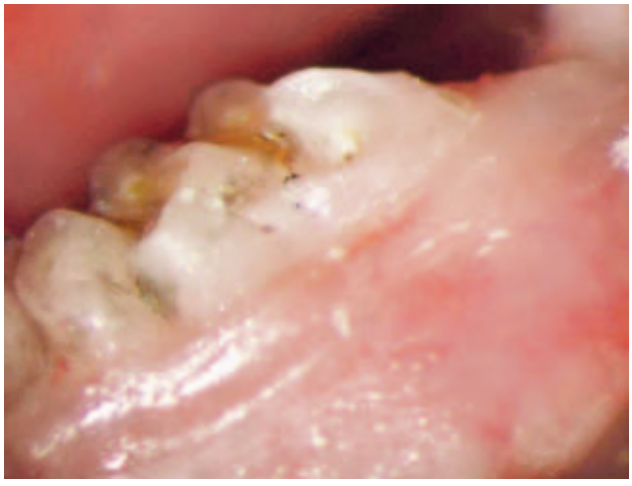

Fig 1c Class I cavities prepared on the buccal surfaces of the first rat molar. Exposure site after laser application.

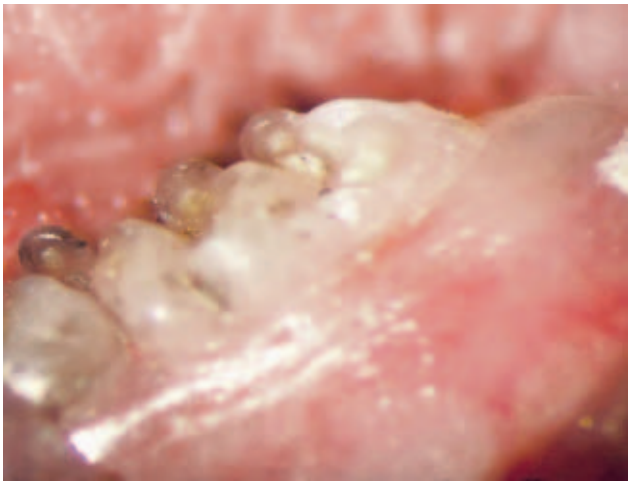

Fig 1d Class I cavities prepared on the buccal surfaces of the first rat molar. Calcium hydroxide placement over the exposure site.

In 2001, Jayawardena et al evaluated the response of accidentally exposed dental pulp in rodents (Wistar rats) to the Er:YAG laser (150 mJ / pulse, 10 pulses of 2.94 μm wavelength and an active part with a diameter of 600 μm) immediately, 3 days, and 2 weeks after treatment. The laser-treated group showed a higher frequency of dentin bridge formation compared to the control group, with $p < 0.01$. The authors consider that further investigations are necessary in order to determine blood extravasation observed near laser exposed sites.[37]

Other authors, for instance, Toomarian, extended the use of Er,Cr:YSGG laser (Waterlase, Biolase, at 20 Hz, 25 mJ per pulse, with a duration of 140 μs for 15 s, power 0.5 W, air cooling 9%), checking its applicability for vital pulpotomy in temporary teeth of dogs.

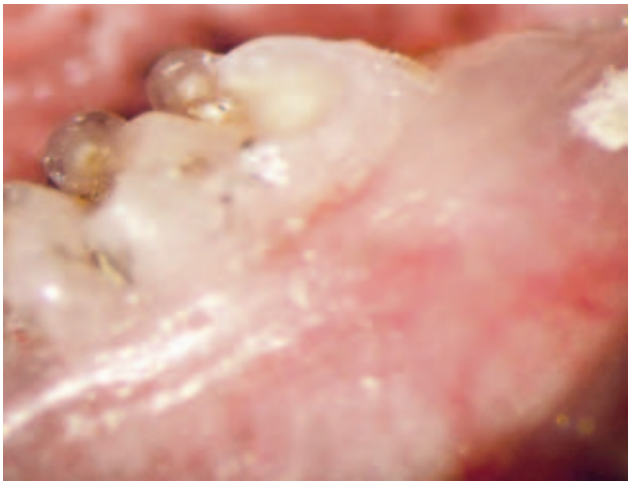

Fig 1e Class I cavities prepared on the buccal surfaces of the first rat molar. Final restoration with glass-ionomer cement.

laser, 1J/ cm^2. His results showed that irradiated animals presented an increased dentin production and closed dentinal tubules. The authors concluded that LPT (Laser Phototherapy) is effective in stimulation of odontoblastic cells, producing reparative dentin and closing dentinal tubules.[76]

(This report will be continued in The Journal of Oral Laser Applications, issue 3, 2008.)

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