Efficacy of Erbium, Chromium-doped:Yttrium, Scandium, Gallium, and Garnet Laser Irradiation Combined with Resin-based Tricalcium Silicate and Calcium Hydroxide on Direct Pulp Capping: A Randomized Clinical Trial

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Abstract

Introduction: The purpose of this randomized clinical study was to evaluate the efficiency of erbium, chromium-doped:yttrium, scandium, gallium, and garnet (Er,Cr:YSGG) laser irradiation combined with a resin-based tricalcium silicate material and calcium hydroxide in direct pulp capping for a 6-month follow-up period. **Methods:** A total of 60 teeth of 60 patients between the ages of 18 and 41 years were recruited for this study. Sixty permanent vital teeth without symptoms and radiographic changes were randomly assigned to the following 4 groups (n = 15): Gr CH, the exposed area was sealed with calcium hydroxide (CH) paste; Gr laser CH, the treated area was sealed with CH paste after Er,Cr:YSGG laser irradiation at an energy level of 0.5 W without water and with 45% air; Gr TheraCal, TheraCal LC (Bisco, Schaumburg, IL) was applied directly to the exposed pulp; and Gr Laser TheraCal, TheraCal LC was applied after irradiation with an Er,Cr:YSGG laser. At the 1-week and 1-, 3-, and 6-month recall examinations, the loss of vitality, spontaneous pain, reactions to thermal stimuli and percussion, and radiographic changes were considered as failure. **Results:** The success rates in the CH and TheraCal groups were 73.3% and 66.6%, respectively. These rates did not reveal any significant difference. In both laser groups, success rates were 100%. The Er,Cr:YSGG laser–irradiated TheraCal and Er,Cr:YSGG laser–irradiated CH groups showed statistically higher success rates than the TheraCal and CH groups, respectively. **Conclusions:** Er,Cr:YSGG laser irradiation at 0.5 W without water combined with pulp capping agents can be recommended for direct pulp therapy. *(J Endod 2016;42:351–355)*

Key Words

Calcium hydroxide, direct pulp capping, erbium, chromium-doped:yttrium, scandium, gallium, and garnet laser, tricalcium silicate

Direct pulp capping is estimated as an efficient treatment procedure that is performed to cover the pulp that is exposed during the removal of carious dentin or by traumatic injuries with a biocompatible material (1, 2). The aim of direct pulp capping is to maintain the vitality of the pulp by preventing bacterial leakage and promoting dentin bridge formation (3). A dentin bridge is a type of tertiary dentin that is secreted by newly differentiated odontoblastlike cells focally at the site of exposed pulp unlike primary and secondary dentin that forms through the entire pulp-dentin interface (4). The process of dentin bridge secretion may be affected by pulp capping materials, the degree of mechanical damage, the occurrence of dentin debris during cavity preparation, inflammation, and bacterial microleakage (5).

Calcium hydroxide (CH)-based materials are the most commonly used pulp capping agents because of their ability to encourage tissue repair by promoting tertiary dentin secretion and to provide antibacterial activity via their high alkaline pH (5). However, CH has some disadvantages such as unstable physical properties; low sealing ability that may lead to bacterial leakage, causing tunnel-like defects during the formation of the dentin bridge; and a lack of adhesion to dentin (4, 6). To overcome these drawbacks, alternative materials like mineral trioxide aggregate (MTA) and tricalcium silicate–based materials have been introduced.

TheraCal LC (Bisco, Schaumburg, IL) is a new light-cured, resin-modified, tricalcium silicate–based material designed for use for direct and indirect pulp capping, aiming to achieve a bond to composite resins and thus reducing microleakage (7). The formulation of TheraCal LC containing tricalcium silicate particles in a hydrophilic monomer provides significant calcium release that stimulates hydroxyapatite and secondary dentin bridge formation (8, 9).

Laser irradiation to the exposed pulp was first performed by Moritz et al (10) using a carbon dioxide laser for the purpose of stimulating dentin bridge formation. The use of a laser for direct pulp capping has been suggested because of the considerable advantages of lasers including the decontamination effect, the biostimulation effect, and the hemostatic and coagulant effect (11–13). The erbium, chromium-doped:yttrium, scandium, gallium, and garnet (Er,Cr:YSGG) laser, which is a relatively new device, has been reported to ablate dental hard tissues thanks to its high absorption in water and the strong absorption by the hydroxyl radicals present in the hydroxyapatite structure (14, 15). Olivi et al (13) stated that erbium-doped:yttrium, aluminum, and garnet (Er:YAG) and Er,Cr:YSGG laser irradiation combined with a self-hardening CH base was effective in improving the prognosis of pulp capping procedures. However, to the best of our knowledge, there is no clinical study regarding the use of the Er,Cr:YSGG laser combined with a resin-modified tricalcium silicate–based material.

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The purpose of this randomized clinical study was to evaluate the efficiency of Er,Cr:YSGG laser irradiation combined with a resin-modified tricalcium silicate–based material and CH in direct pulp capping performed on the exposed pulps of permanent teeth for a 6-month follow-up period.

Materials and Methods

Sixty patients (42 men and 18 women) between the ages of 18 and 41 years (mean age = 28 years) who had undergone conservative treatment for deep caries in their permanent teeth were recruited for this randomized clinical study. Patient recruitment was performed within the Department of Restorative Dentistry, Faculty of Dentistry, Near East University, Mersin, Turkey. After having received oral and written information about the goals and design of the study and having signed the informed consent form, the subjects were included in the study. Study protocol and related consent forms were approved by the institutional review board of the university.

In all patients, the pulp had been exposed because of caries removal. The following selection criteria were used in this research:

1. Permanent teeth with deep caries (remaining dentin thickness <0.5 mm); the thinnest point of the remaining dentin on the floor of the lesion and the pulp dentin border was assessed as the remaining dentin thickness, and it was measured by Dimaxis Imaging Software (Dimaxis Pro 4.1X; Planmeca, Helsinki, Finland) on the radiographs
2. No clinical symptoms
3. Vital teeth (the vitality of the teeth was assessed with an electric pulp tester [Digitest, Parkel, NY]) before the treatment)
4. No periapical radiographic changes
5. Diameter of the exposed area between 0.5 and 1.5 mm

Criteria for exclusion from the study were spontaneous pain, tenderness to percussion and palpation, bleeding lasting over 3 minutes after exposure, periapical radiographic changes such as periradicular or furcal radiolucency, a widened periodontal ligament space, and resorption.

A total of 60 teeth (38 premolars and 22 molars) from 60 patients were randomly divided into 4 groups according to the type of treatment (n = 15). All of the cavities were prepared with traditional rotating instruments under local anesthesia with rubber dam isolation by a single operator who had specialized in restorative dentistry.

CH Group

After hemostasis was achieved by placing a sterile cotton pellet dampened with sterile saline gently onto the exposure site for 15 seconds, the exposed area was sealed with a self-hardening CH paste (Dycal; Dentsply, Tulsa, OK).

Laser CH Group

The exposed area was irradiated with the Er,Cr:YSGG laser (Waterlase MD; Biolase, Irvine, CA) on hard tissue mode with an MG6 sapphire tip using the noncontact mode at an energy level of 0.5 W, a repetition rate of 20 Hz, and a 140-μs pulse duration with 0% water and 45% air for 10 seconds. After laser irradiation, the treated area was sealed with a self-hardening CH paste.

TheraCal Group

After hemostasis was achieved, the light-cured resin-based tricalcium silicate pulp capping material (TheraCal LC) was applied directly to the exposed pulp with a needle tip syringe in incremental layers that were not to exceed 1 mm in depth. All the exposed areas were covered, and TheraCal was extended at least 1 mm onto sound dentin surrounding the exposure area. Each 1-mm increment layer was light cured with a quartz-tungsten halogen light-curing unit (Hilux UltraPlus; Benlioglu Dental, Ankara, Turkey) in standard mode with an intensity setting of 700 mW/cm^2 for 20 seconds.

Laser TheraCal Group

After the exposed area was irradiated with the Er,Cr:YSGG laser with the same parameters as the laser TheraCal group for 10 seconds, TheraCal was used to seal the treated area.

For all groups, a resin-modified glass ionomer (GC Fuji II LC; GC Corp, Tokyo, Japan) was placed over the pulp capping materials, and then the final restoration was completed using a nanohybrid composite resin (Clearfil Majesty Posterior; Kuraray Medical Inc, Tokyo, Japan) with a self-etch adhesive system (Clearfil SE Bond, Kuraray Medical Inc) at the same session. Recall examinations were performed after 1 week and at 1, 3, and 6 months. Clinical failure criteria included the loss of vitality, spontaneous pain, reactions to thermal stimuli, and tenderness to percussion. Periradicular or furcal radiolucency, a widened periodontal ligament space, and resorption examined at the 6-month radiographic examination were classified as radiographic failure. Radiographic assessments were performed by a calibrated dentist who was also blind to the type of treatment groups. The clinical failures and radiographic failures were determined as the total failure.

The 95% confidence intervals for the success rates of all groups were calculated. A Kaplan-Meier survival curve was used to investigate differences in the success rates. Pair-wise comparison was performed when significance was detected. Survival times were calculated from the date of treatment to the date of last contact or the date of "failure." To analyze the failed cases, the log-rank test was conducted according to the capping method. P values <.05 were considered statistically significant.

Results

Sixty patients with 60 teeth were included in this randomized clinical trial, and all of the patients took part in the 6-month follow-up examination (patient recall rate = 100%). The overall success rate was 85% (51/60 cases), and the success rates in the CH and TheraCal groups were 73.3% (11/15 cases) and 66.6% (10/15 cases), respectively. The failed cases and their characteristics are described in Table 1. Statistical analysis of these success rates did not reveal any significant difference between the CH and TheraCal groups (Table 2).

In both laser groups, the success rates were 100%. The Er,Cr:YSGG laser–irradiated TheraCal group and the Er,Cr:YSGG laser–irradiated CH group showed statistically higher success rates than the TheraCal and CH groups, respectively.

Discussion

The dental pulp may be exposed because of deep caries, trauma, or iatrogenic procedures. The response of the pulp to exposure may vary according to the etiologic factor and the depth of the lesions or fracture (16). Raslan and Wetzel (17) stated that pulp exposed by trauma showed fewer inflammatory reactions and no retrogressive pulp changes in comparison with the pulp exposed because of caries. With that in mind, only permanent teeth exposed by deep caries were recruited for this study.

The length of time necessary for adequate postoperative follow-up is unclear. Matsuo et al (18) suggested that 3 months was adequate for tentative prognosis because the success rates of the groups having postoperative follow-up periods of 3 to 18 months were similar. Also, previous studies (10, 19, 20) that evaluated the effect of capping materials

TABLE 1. The Failed Cases and Their Characteristics

Case	Age	Sex	Tooth type	Capping material	When failure noted	Reasons for failure
1	28	M	Premolar	CH	1 month	Clinical symptoms
2	36	M	Molar	CH	3 months	Fracture
3	27	F	Molar	CH	3 months	Clinical symptoms
4	19	M	Molar	CH	6 months	Pulp necrosis
5	22	M	Premolar	TheraCal	1 month	Clinical symptoms
6	24	F	Molar	TheraCal	1 month	Fracture
7	41	F	Molar	TheraCal	1 month	Clinical symptoms
8	29	M	Premolar	TheraCal	3 months	Pulp necrosis
9	34	F	Molar	TheraCal	6 months	Clinical symptoms

CH, calcium hydroxide; F, female; M, male.

had postoperative follow-up periods less than 4 months, and in that period, prognosis and determinations were presented as success or failure for CH and MTA materials. Taking into consideration previous studies (10, 18–20), in the present study the short-term clinical outcomes observed at the 6-month follow-up were found to be sufficient to make tentative prognosis of the final restorations. However, long-term clinical outcomes are necessary to prove the reliability of direct pulp capping with TheraCal and the Er,Cr:YSGG laser.

Factors such as age, caries history, location, and blood clotting between the pulp and the capping material have been reported to affect the prognosis of the treatment (21, 22). The influence of age on the success or failure of pulp-capped teeth is controversial in the literature. Some clinical studies (22, 23) have recommended that the age of the patient should be considered to perform direct pulp capping because of the high healing potential of pulp tissue in young patients compared with old patients, whereas other studies (18, 24) have not reported lower success rates with increasing age. In this study, the ages of the patients are young and very close to each other, so the effect of age on the success or failure of pulp-capped teeth could not be evaluated.

Direct pulp capping of carious-exposed pulps has been considered to be doubtful because of the varying clinical success rates of CH-based materials (21). CH is used as the gold standard in pulp capping procedures because of its beneficial properties such as the induction of mineralization and the inhibition of bacterial growth (25); however, tunnel defects and cell inclusions in dentin bridges formed by CH may lead to leakage and bacteria penetration, resulting in the loss of vitality (26). In a previous retrospective study (24), 37% and 13% success rates of direct pulp capping with CH were reported after 5 and 10 years, respectively, whereas a previous clinical study (18) presented 81.8% (followed-up for >3 months) and 80.0% (followed-up for >6 months) success rates. These results showed that studies with longer follow-up periods exhibited lower success rates. In this study, the success rate of direct pulp capping with CH was 73.3% (11/15 teeth). The discrepancies between these results may be attributed to treatment modalities like using permanent or temporary restorations, the skill of the operators, the site of exposure, pulpal health before treatment, the number and characteristics of the patients recruited to the study, and follow-up periods.

Recently, MTA has become an alternative material for direct pulp capping (20, 21). A previous clinical trial (20) reported that MTA and Endocem, which is an MTA-derived pozzolan cement, showed 95.5% and 90.5% success rates, respectively. Consistent with these results, Marques et al (21) reported a 91.3% overall success rate for direct pulp capping with MTA. These higher success rates of MTA compared with the rates of CH and TheraCal LC evaluated in this study may be related to the chemical and physical properties, antibacterial activity, biocompatibility, and favorable sealing properties of MTA (20).

One of the new materials that was introduced to overcome the disadvantages of CH was TheraCal (9). The presence of a resin matrix modifies the setting mechanism and calcium ion leaching of TheraCal. Camilleri (7) found that TheraCal did not exhibit any formation of CH on hydration, and calcium phosphate was deposited over the surface. Gandolfi et al (9) reported that TheraCal released significantly more calcium ions than MTA and Dycal, and this ability could favor the formation of apatite and induce the differentiation of odontoblasts with the formation of new dentin. In a previous study, Cannon et al (27) showed that primate pulps with TheraCal created thicker dentin bridges compared with CH and showed mild inflammation acceptable for pulp capping. There is no clinical study available that investigated the treatment outcomes of direct pulp capping with TheraCal. Considering the results of previous *in vitro* studies (7, 9, 28) that have reported beneficial properties of TheraCal, higher success rates were expected for this tricalcium silicate–based material. However, in the present study, lower favorable treatment outcomes for direct pulp capping with TheraCal were found when compared with CH clinically. This result may be related to the short-term follow-up period.

In the present study, the Er,Cr:YSGG laser–irradiated TheraCal and Er,Cr:YSGG laser–irradiated CH groups showed higher success rates than the TheraCal alone and CH alone groups. These results are in agreement with those of previous studies that concluded

TABLE 2. Pair-wise Comparison between Pulp Capping Material and Success Rates for All Treatment Groups (*P* values)

	CH	Er,Cr:YSGG laser + CH	TheraCal LC	Er,Cr:YSGG laser + TheraCal LC
CH	—	<.05*	>.05	<.05*
Er,Cr:YSGG laser + CH	<.05*	—	<0.05*	>.05
TheraCal LC	>.05	<.05*	—	<.05*
Er,Cr:YSGG laser + TheraCal LC	<.05*	>.05	<.05*	—

CH, calcium hydroxide; Er,Cr:YSSG, erbium, chromium-doped:yttrium, scandium, gallium, and garnet.

*Statistical significance.

that laser-assisted direct pulp capping has significant benefits in comparison with conventional procedures (10, 11, 29). The use of lasers for direct pulp capping has been suggested because of the considerable advantages of lasers including the biostimulation effect, the decontamination effect, and the hemostatic and coagulant effect (11–13, 30). Utsunomiya (29) reported that low-power laser irradiation accelerates wound healing of the exposed pulp in dogs by forming a fibrous matrix and dentin bridge earlier than the nonirradiation group. Consistent with this result, Jayawerdena et al (31) showed that a homogenous dentin bridge was formed at a faster rate by odontoblastoid cells, which were differentiated from pulp cells in rats after Er:YAG laser irradiation. The high success rates of Er,Cr:YSGG laser–assisted pulp capping in this study may be related to the benefits provided by the biostimulation effect of the Er,Cr:YSGG laser. However, there is no histologic study regarding the pulpal response to exposure with an Er,Cr:YSGG laser; therefore, it may be suggested that Er,Cr:YSGG shows healing capacity by forming a dentin bridge and reparative dentin with the same mechanism as the Er:YAG laser because the wavelength (2.94 mm) of the Er:YSGG laser is very close to the Er:YAG laser, resulting in similar effects (14, 15).

Er,Cr:YSGG laser irradiation provides a precise cut of hard and soft tissues through the interaction of laser energy with atomized water droplets on the tissue interface, resulting in ablation of the tissue (14). Meister et al (32) reported that not only the existing water in tissue but also the exogenous water was used by the Er,Cr:YSGG laser for ablation, and the effect of exogenous water is greater than endogenous water; therefore, in the present study, the Er,Cr:YSGG laser was used without water to avoid ablation. Besides the presence of water, it has been reported that the output power of laser energy also plays an important role for dentin ablation, and ablation efficiency increased in proportion to the power setting of the laser (33). With that in mind, in the present study, the Er,Cr:YSGG laser was irradiated with lower-energy settings than the threshold at which carbonization and melting could occur.

The high bactericidal potential of the Er,Cr:YSGG laser (33) should be also emphasized because the presence of bacteria in the pulp is associated with inflammation and pulp pathologic features that may affect the healing process (4, 5). In a previous study (30) that assessed the effectiveness of the Er,Cr:YSGG laser in direct pulp capping, exposed pulps were treated at 1 W with 55% water and 65% air to achieve a bactericidal effect. On the other hand, Franzen et al (34) stated that Er,Cr:YSGG laser irradiation with an output power of 0.25 W without water resulted in significant bacterial reduction in deep dentin. In the present study, the bactericidal effect achieved with Er,Cr:YSGG laser irradiation at 0.5 W may be responsible for the greater success rate of laser-assisted pulp capping.

It is also noteworthy that hemorrhage control at the exposure site is critical for the success of the pulp capping treatment because increased bleeding can indicate the degree of inflammation in the pulp, resulting in a diminished capacity for repair (11). Moritz et al (10) suggested that laser irradiation should minimize the formation of a hematoma between the pulp tissue and pulp capping agent, allowing close contact. Hemorrhage was effectively controlled by the Er,Cr:YSGG laser because of the significant absorption of laser light by hemoglobin and melanin as reported by a previous study (35). However, strict hemostasis could not be achieved by the Er,Cr:YSGG laser, and the hemostatic area was more superficial when erbium lasers were used compared with diode lasers (11). In the present study, this limited ability could not be considered as a disadvantage because exposed pulp bleeding lasting over 3 minutes after exposure was not included in the study, so strict hemostasis was not required.

Conclusion

According to the results of this randomized clinical study, TheraCal and CH showed similar survival rates at the 6-month follow-up period. Er,Cr:YSGG laser irradiation at 0.5 W without water combined with pulp capping agents can be recommended for direct pulp capping. However, further studies with larger sample sizes and longer follow-up periods are needed to prove the effectiveness of the Er,Cr:YSGG laser in direct pulp capping.

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The authors deny any conflicts of interest related to this study.

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