Pulp capping, as an elective procedure, can be viewed as representing a borderline between restorative and endodontic dentistry. Where possible, the maintenance of pulp vitality greatly improves the dental prognosis, from both a biomechanical and esthetic point of view. Research into new techniques and technologies in order to enhance success can therefore be justified.

A review of published literature reveals that the high success rates reported refer to pulp capping on fractured anterior teeth\textsuperscript{1,2} with an important correlation with age, while molars\textsuperscript{3,4} treated for deep decay present much lower success rates.

The most recent studies report long-term success rates close to 90\% for laser-assisted pulp capping, compared to a success rate of about 60\% with traditional methods. In 1997, Santucci\textsuperscript{5} recorded a success rate of 90\% after 54 months using a Nd:YAG laser, compared to the control group. Moritz\textsuperscript{6,7} conducted two studies using a pulsed CO\textsubscript{2} laser and reported success rates of 93\% and 89\% respectively, compared to the control group which used traditional methods and calcium hy-
droxide. Studies performed by Jayawardena with an erbium laser demonstrated good healing capacity with the formation of a dentin bridge and repaired dentin.

Cohen and Burns have defined the treatment as follows: “pulp capping is the application of a medication or dressing to the exposed pulp in an attempt to preserve vitality”. In addition, Ingle stated: “direct pulp capping is the protection of a pulp exposed... through trauma to the anterior teeth, accidental mechanical exposure during tooth or cavity preparation or deep dentinal decay”.

**Indications**

A successful outcome of restorative treatment, inclusive of necessary pulp capping, partial pulpotomy, and cervical pulpotomy, is dependent on following protocols based on the presenting criteria. Such criteria include:

- the recent dental history in the case of deep cavities (without symptoms or with mild sensitivity to heat stimulation)
- the time between trauma and treatment (24 to 48 h)
- the patient’s age
- the maturity of the tooth
- the condition of the pulp tissue (active hyperemia and/or reversible pulpitis) and the amount of bleeding (indicative of irreversible pulp change)
- the dimensions and the location of exposure (0.5 to 1.5 mm, coronal site) (Figs 1 and 2)

**Contraindications**

Where radiographic examination reveals thickening of the apical periodontal ligament, or there is excessive dental mobility, heavy bleeding, or the excretion of pus from the pulp cavity, a pulp capping procedure is not indicated.

**Diagnosis**

Diagnostic examination to assist in treatment planning includes:

- thermal and electric tests
- objective exam (the absence of mobility and pain upon percussion)
- radiographic examination.

**Pulp Capping Agent**

Traditional techniques make use of calcium hydroxide, the properties of which are already well known (Table 1). Recently, the use of mineral trioxide aggregate
(MTA)\textsuperscript{11} has been introduced; its pH and biocompatibility are similar to calcium hydroxide, but its greater sealing capacity and duration in situ prolong its necrotizing action on the pulp, allowing the formation of a more apical dentinal bridge. Reduced ease of manipulation, higher cost, and the necessity of performing the restoration at a later appointment tend to restrict the use of MTA to treating root perforations or apical fillings in endodontic surgery.\textsuperscript{12}

The purpose of this study was to evaluate the efficacy of the physical action of the Er,Cr:YSGG laser combined with a base of calcium hydroxide to improve the clinical outcome of pulp capping procedures.

**MATERIALS AND METHODS**

In this study an Er,Cr:YSGG laser (2780 nm, Waterlase YSGG, BioLase Technology; San Clemente, CA, USA) was used. In all teeth treated, a G6 sapphire handpiece tip (600 μm) was used, combined with a base of calcium hydroxide.

The patients treated for the pulp capping procedure were selected according to the indications given above. A total of 25 carious teeth (20 posterior and 5 anterior teeth) were divided into 2 groups and treated with pulp capping. Group A comprised 13 teeth without macroscopically evident pulp exposure, and group B comprised 12 teeth with pulp exposure (0.5 > 1.5 mm) (Table 2). The age of the 25 patients ranged from 15 to 40 years, with one patient aged 56 years (Table 3).

After completing the cavity preparation with the laser, cases without pulp exposure (group A) were treated with the laser at 1 W, 20 pps, 50 mJ, for 60 s (water 55%, air 65%) in focused mode (1.5 mm) to achieve a bactericidal effect, and at 1 W, 20 pps, 50 mJ, for 30 s (water 15%, air 25%) in defocused mode to perform dentin melting (Fig 3).

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**Table 1 Comparison of pulp capping agents**

<table>
<thead>
<tr>
<th>Calcium hydroxide</th>
<th>Mineral trioxide aggregate (MTA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biocompatible</td>
<td>Biocompatible</td>
</tr>
<tr>
<td>Fairly good seal</td>
<td>Good seal</td>
</tr>
<tr>
<td>Soluble</td>
<td>Insoluble</td>
</tr>
<tr>
<td>Promotes dentinal bridge</td>
<td>Promotes dentinal bridge</td>
</tr>
<tr>
<td>Bacteriostatic action</td>
<td>Bacteriostatic action</td>
</tr>
<tr>
<td>pH 10.5-12.5</td>
<td>pH 12.5</td>
</tr>
<tr>
<td>Needs dry field</td>
<td>Needs wet field</td>
</tr>
<tr>
<td>Easy to remove</td>
<td>Difficult to remove</td>
</tr>
<tr>
<td>Economical</td>
<td>Expensive</td>
</tr>
<tr>
<td>Doesn’t change tooth color</td>
<td>Can stain the tooth</td>
</tr>
<tr>
<td>Predictable and tested</td>
<td>Long-lasting action (?)</td>
</tr>
</tbody>
</table>

**Table 2 Description of teeth treated**

<table>
<thead>
<tr>
<th>Group A</th>
<th>11 posterior teeth</th>
<th>without macroscopically evident pulp exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>2 anterior teeth</td>
<td>without macroscopically evident pulp exposure</td>
</tr>
<tr>
<td>Group B</td>
<td>9 posterior teeth</td>
<td>with pulp exposure 0.5 &gt; 1.5 mm</td>
</tr>
<tr>
<td>Group B</td>
<td>3 anterior teeth</td>
<td>with pulp exposure 0.5 &gt; 1.5 mm</td>
</tr>
</tbody>
</table>

**Table 3 Patient age and number**

<table>
<thead>
<tr>
<th>Group</th>
<th>Age Range</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>15 – 25 years</td>
<td>6</td>
</tr>
<tr>
<td>Group A</td>
<td>26 – 40 years</td>
<td>7</td>
</tr>
<tr>
<td>Group B</td>
<td>15 – 25 years</td>
<td>6</td>
</tr>
<tr>
<td>Group B</td>
<td>26 – 40 years</td>
<td>5</td>
</tr>
<tr>
<td>Group B</td>
<td>&gt; 40 years</td>
<td>1</td>
</tr>
</tbody>
</table>
Cases with pulp exposure (group B) were treated with the same parameters as above for cavity preparation and disinfection, followed by a defocused irradiation at 0.5 W, 20 pps, 25% air, 15% water in defocused mode.

After laser irradiation, the treated area was protected with a base of pure calcium hydroxide in group A, or with self-curing calcium hydroxide in group B. In all cases, restoration was completed with an adhesive system (Scotchbond Mult-Purpose, 3M; St. Paul, MN, USA) to obtain dentin sealing (Fig 5), and a microhybrid composite (Enamel Plus, GDF; Rosbach, Germany).

RESULTS

No significant difference was found between groups A and B. Two out of 12 treated cases with direct pulp capping failed after 12 months; 2 out of 13 treated cases without pulp exposure failed after 48 months, with a total success rate of 84% (Table 4).

A difference was found between anterior and posterior teeth: all 5 anterior teeth (100%) treated with the Er,Cr:YSGG laser maintained their vitality after 48 months; 16 of the 20 posterior teeth (80%) treated maintained vitality after 48 months. No difference was found based on the age of the patient.

The outcome was judged successful if pain was absent, periapical lesions in the roots were absent, and there was evidence of the formation of a dentinal bridge (clinical history, pulp vitality test, radiographic exams).

DISCUSSION

The use of the Er,Cr:YSGG laser allows cavity preparation to be completed with only one instrument, in contrast to the alternate use of high- and low-speed rotary instruments and other laser wavelengths (CO₂, Nd:
YAG, and diode lasers), which cannot be used for ablation of hard tissue.

When using the Er,Cr:YSGG laser in pulp capping to create the biological base for the formation of a sterile area, the creation of a dentinal bridge, and for the maintenance of pulp vitality, the following may be considered as contributing effects:

1. The sterile area is due to the bactericidal effect of the laser, an effect common to all wavelengths. There are many studies that have demonstrated the bactericidal power of lasers\(^\text{13,14}\) but it is important to emphasize the different action of different lasers and the different depths of penetration in the target tissue. The CO\(_2\) and the erbium group of lasers are more superficial in their interaction with tissue than the diode and Nd:YAG wavelengths, which penetrate more deeply (up to 500 to 1000 \(\mu\)m)\(^\text{15}\) and have a greater capacity for scattering (Fig 6). The decontaminating action of the laser, more or less superficial, must be completed with immediate sealing of the exposed pulp area to avoid recontamination through leakage.

2. The coagulating effect of the laser guarantees a dry operating area, with no bleeding and the creation of a zone of necrosis that is more superficial compared to a chemical pulp capping agent\(^\text{12}\) (Fig 7). Significantly, different lasers have different hemostatic or coagulating effects due to the differences in absorption by the target tissue (pigment, water, or dentin) (Figs 8 to 10).

3. Only the use of the erbium laser (2780 to 2940 nm) limits a pressure increase in the dental cavity, thus avoiding the risk of pushing either mechanically or manually the infected dental chips into the pulp tissue during caries removal.\(^\text{9}\)

4. The use of the erbium laser, compared to lasers with other wavelengths and compared to traditional mechanical rotating instruments, limits temperature increase in the pulp chamber and may even produce a decrease.\(^\text{16,17}\)

5. In the case of a near-exposure of pulpal tissue but without macroscopically evident exposure, a soft, gentle irradiation of this limited area with a moderate, controlled thermal effect allows the formation of a barrier against bacterial contamination and chemical/mechanical stimuli of the pulp tissue. With SEM examination, the obliteration of the dentinal tubules, creating a limited area of melting that protects the underlying pulp, can be observed (Fig 11) (Olivi G, 12th ALD Conference, New Orleans, LA, USA, April 6-8, 2005).

The use of the erbium laser is also important for its selective ablation of caries, minimally invasive preparation, and the possibility of reducing the use of local anesthesia (Figs 12 to 18).

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**Table 4 Clinical results (failure/success)**

<table>
<thead>
<tr>
<th>Group</th>
<th>Survival After 48 Months</th>
<th>Failure</th>
<th>Success</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>84%</td>
<td>4/25</td>
<td></td>
</tr>
<tr>
<td>Posterior teeth</td>
<td>80%</td>
<td>4/20</td>
<td></td>
</tr>
<tr>
<td>Anterior teeth</td>
<td>100%</td>
<td>0/5</td>
<td></td>
</tr>
<tr>
<td>Group A</td>
<td>84.6%</td>
<td>2/13</td>
<td></td>
</tr>
<tr>
<td>Group B</td>
<td>83.3%</td>
<td>2/12</td>
<td></td>
</tr>
</tbody>
</table>

**Fig 6** Different laser/tissue interaction of near, medium and far infrared wavelength. Erbium and CO\(_2\) laser have a superficial interaction with target tissue. Diode and Nd:YAG laser have a body interaction with the target tissue, resulting in deeper penetration and a high capacity for scattering.
Fig 7a  Graphic representation of laser-assisted pulp capping and of formation of dentinal bridge.

Fig 7b  Laser/tissue interaction.

Fig 7c  Laser/tissue interaction. N: necrosis area 80°C; C: coagulation area 60°C; W: warming area of reversible damage 35 to 50°C, stasis of capillaries and migration of leukocytes.

Fig 7d  Application of a base of calcium hydroxide (CH), immediate filling with flowable composite (F) and microhybrid composite (C); the fibroblasts migrate in the zone under calcium hydroxide, where the dentinal bridge will form.

Fig 7e  After some weeks calcification begins.

Fig 7f  Odontoblasts (O) in the dentinal bridge zone: almost calcified dentin and almost normal pulp.
**Fig 8** Pulp exposure (tooth 16) with moderate bleeding. Coagulation performed with diode 810-nm laser (0.8 W, cw in defocused mode).

**Fig 9** Pulp exposure (tooth 23) with absence of bleeding. Coagulation performed with Er:YAG laser (0.21 W, 3 pps, 70 mJ, no water-air cooling) in defocused mode.

**Fig 10** Intra-operative view. Microscope image 40X (tooth 16): area of dentin vitrification performed with Er,Cr:YSGG laser.

**Fig 11** SEM image (2200X) of melting with partial closure of dentinal tubules performed with Er,Cr:YSGG laser. In vitro sample control.

**Fig 12** Clinical case: occlusal decay of teeth 26, 27 in 20-year-old male patient.

**Fig 13** Pre-operative radiograph, showing a deep cavity on tooth 27.
Fig 14 Cavity preparation performed with Er,Cr:YSGG laser.

Fig 15 (left) After the cavity finishing and checking, a small pulp exposure on tooth 27 appeared. (right) Laser coagulation and capping with self-curing calcium hydroxide.

Fig 16 (left) Enamel acid etching (37% orthophosphoric acid for 15 s). (right) Enamel and dentin total-etching (37% orthophosphoric acid for 15 s).

Fig 17 Composite resin restoration.

Fig 18 One-year postoperative radiograph.
CONCLUSION

Laser use in restorative dentistry not only allows an improvement in patient approach (no contact, no vibration, reduced need of anesthesia), but also improves the prognosis in treatments such as pulp capping, where maintaining dental vitality is a determining factor in clinical success. For their bactericidal and coagulating effect, all wavelengths, even with different effects and usage, can be used effectively in this procedure.

In our experience, the use of the Er,Cr:YSGG laser (2780 nm) allows us to combine the advantages of laser preparation of the tooth with the treatment of pulp exposure.

ACKNOWLEDGMENTS

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REFERENCES