Cavity Preparation Using a Superpulsed 9.6-μm CO_2 Laser—A Histological Investigation

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Background and Objectives: The superpulsed 9.6-μm CO_2 laser is an effective laser for ablating dental tissues and decay. This histological study compares laser class V preparations with conventional treatment to evaluate the resulting formation at the cavity walls.
Study Design/Materials and Methods: Four class V preparations (one made with a diamond drill and three with the CO_2 laser (9.6 μm, 60 microseconds pulse width, 40 mJ pulse energy, 100 Hz, integrated scanner system, water cooling) were performed on ten extracted teeth. The cavities were filled with a composite resin partly including enamel and dentine conditioning.
Results: After laser preparation, no cracks or signs of carbonisation were detected. The results were comparable to those attained with conventional treatment. Following cavity filling without prior conditioning, gaps were noted at the cavosurface indicating a lack of adhesion. Dentinal bonding decreased gap formation significantly.
Conclusion: The 9.6-μm CO_2 laser is an effective tool for cavity preparation. Lasers Surg. Med. 30:331–336, 2002. © 2002 Wiley-Liss, Inc.

Key words: CO_2 laser; composite filling; dentistry; tissue ablation

INTRODUCTION

The growing interest in dental laser surgery has led to an increasing number of studies on hard tissue treatment [1]. The categorical prediction made by Stern, more than twenty years ago, that the laser would not replace the dental drill unless radical improvements were made, remains a challenge to both basic research and clinical practice [2]. In the years since that statement was made, a substantial difference has been observed in the impact of the laser on soft and hard oral tissues, respectively. Soft tissues are apparently able to heal without significant delay even when zones of necrosis and carbonisation are evident immediately after laser treatment.

In contrast, the pulp-dentine complex and the periodontium have a very limited regenerative potential and the enamel none, making it essential to minimise any adverse side effects of the laser if dental health is to be maintained.

A number of laser systems have been investigated for hard tissue applications. However, many of these applications resulted in damage due to an excessive increase in temperature [3]. In some systems a water spray is used to make the removal of hard dental issues more efficient and safe [4–6]. To avoid or minimise the side effects of dental tissue ablation, the conduction of heat from the cavity surface to the dentine and pulpal tissues has to be restricted. These effects are directly related to the energy absorption of the irradiated tissues, pulse duration and the thermal relaxation characteristics of the ablative process [4,6].

CO_2 laser light is reasonably well absorbed by enamel and dentine [7–9]. It has recently been demonstrated that CO_2 laser light with a wavelength of 9.6 μm is superior to light with a wavelength of 10.6 μm for ablating dentine due to the higher absorption of this kind of light by dental hard tissues [10–12]. Laser light with a wavelength of 9.6 μm is strongly absorbed not only by water, but also by the other organic and inorganic structures of both dentine and enamel [13]. Absorption is the basic precondition for effective and safe laser ablation.

To prevent a rise in the temperature of hard tissue structures, the optimum pulse duration has to be set close to the thermal relaxation time of the tissue. The repetition of pulses in a limited tissue volume may lead to cumulative thermal effects; as a result, the distribution of pulses in a larger tissue volume is preferable. A scanner system can reduce cumulative thermal effects by permitting a more controlled energy distribution [14].

Merging high absorption, short pulse duration and the use of a scanner system in tissue ablation may result in synergistic effects.

To study the effects of the laser at the cavosurface, cross sections of the irradiated samples are required. Side effects such as charring, cracking or heat-induced denaturation and the resulting surface morphology can then be analysed [15]. In histological studies, paraffin or cryo-techniques

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Accepted 27 February 2002
Published online in Wiley InterScience (www.interscience.wiley.com).
DOI 10.1002/lsm.10063

are used for cut cross sections. Mineralised tissues usually must be decalcified before sections are cut for histological analysis. As a result of this process, many laser-induced alterations in dentine and enamel—and the bonding effects occurring after filling procedures—cannot be evaluated. To circumvent these disadvantages, sawing and grinding techniques were developed for cutting non-decalcified sections. When working with specimens that cannot be processed with paraffin techniques without decalcification, it is vital to cut thin sections for histological interpretation after drilling and filling [16].

The objective of this study was to examine the side effects of CO_2 laser cavity drilling histologically by comparing the results of conventional treatment with the results obtained using a superpulsed CO_2 laser system with a complementary scanner system and water spray.

MATERIALS AND METHODS

The specimens were taken from freshly extracted, caries free human third molars. Before being embedded for histological examination, the teeth were always stored in saline solution to prevent the specimens from drying. NaN_3 (0.01‰) was added to inhibit bacterial growth.

For cavity preparation, a superpulsed carbon dioxide laser (ESC-Sharplan, Sharplan Laser Industries, Tel-Aviv, Israel) emitting light with a wavelength of 9.6 μm was used. The laser parameters were: 60 microseconds pulse width and 40-mJ pulse energy. The repetition rate was set at 100 Hz. An integrated scanner system allowed for controlled ablation of a 2.5-mm broad area. The scanner system delivered a series of single pulses (300 μm spot size) in a hexagonal pattern. The built in water-cooling spray was set to 15 ml of water per minute. Water-cooling started 3 seconds before active radiation and ended 3 seconds after termination.

As a control, a conventional dental handpiece (Intra Lux 3, KaVo dental GmbH, Biberach, Germany) and diamond drills (ISO 806 314 140524 016, ISO 806 314 257504 023 Hager & Meisinger, Duesseldorf, Germany) were used for cavity preparation. The drilling parameters were: 120,000 rpm and 50 ml of water spray per minute for cooling.

Four class V preparations (three with the CO_2 laser, and one with the diamond drill) were made at the buccal and lingual sites of 10 teeth (Fig. 1). The diameter of the cavities averaged about 3 mm, the depth 3.5 mm. The margins of the cavities were bevelled; the outline of the cavities was formed according to the rules of adhesive dentistry. Test and control sites were randomly selected. The resulting 40 cavities were divided into 4 groups (Table 1). The control group was drilled with the diamond bur and filled with the Tetric® resin system; acid etching of enamel and dentine bonding (Syntac®) were carried out according to the manufacturer's instructions (Table 1). As an optimum resin type, Tetric-flow was used due to the diameter of the cavities. In the three laser groups the etching/conditioning procedure was varied to show whether enamel etching or dentinal bonding is needed after laser preparation (Table 1). One group of specimens was filled without any conditioning, another without enamel etching. The third group was filled according to the procedure used in the control group. All specimens were subjected to 2,000 thermal cycles between 6, 36, and 60°C with a dwell time of 60 seconds in each water bath.

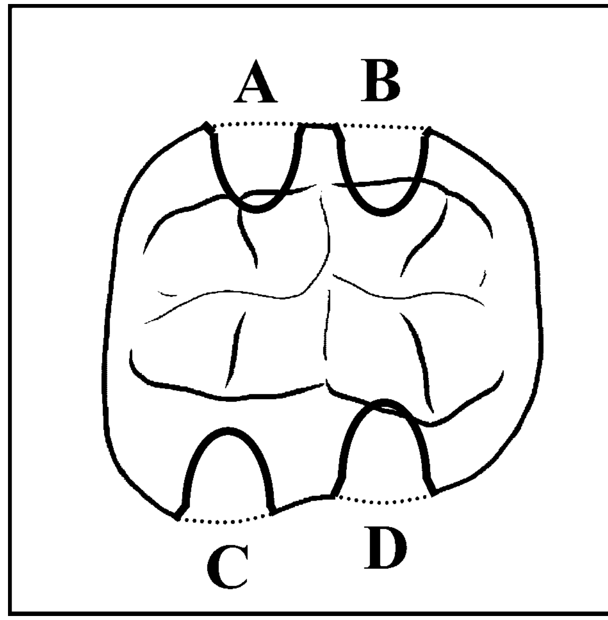

Fig. 1. Experimental design: location and outline of the four cavities/teeth.

For the purpose of histological analysis the teeth were cut using sawing and grinding techniques [16]. Following fixation for three days in 10% formalin, dehydration of the specimen was achieved by using successive alcohol and 2-hydroxyethylmethacrylate (GMA) concentrations.

An ultraviolet light-activated polymethylmethacrylate (PMMA) (Technovit 7200® VLC) was used as the infiltration medium. The Technovit 7200 VLC was photopolymerised in three steps to minimise artifacts caused by polymerisation shrinkage. High power UV light sources were needed in the last stage of polymerisation to make sure that the medium was fully hardened. To ensure that the temperature of the tissues did not exceed 40°C during photopolymerisation, cooling devices were employed (ELPU®). Parallel sections of 100 μm thickness were cut from the specimens in a microsawing machine (ETS®). The desired final thickness of the specimens (15 μm) needed for light microscopic analysis was obtained by

TABLE 1. Experimental Design of the Study

Group (n = 10)	Mode of preparation	Acid etching	Dentine conditioning
1	Diamond	+	+
2	Laser	−	−
3	Laser	+	+
4	Laser	−	+

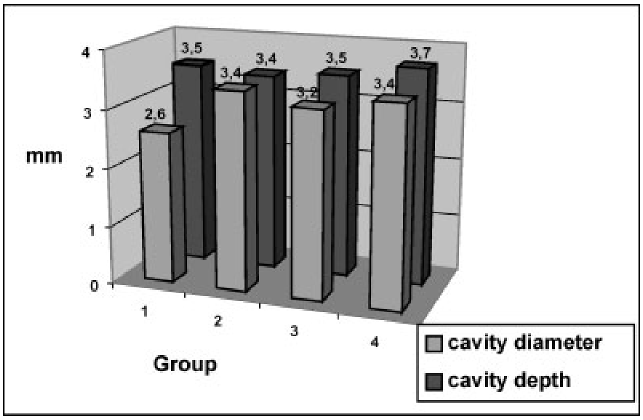

Fig. 2. Depth and diameter of the cavities.

TABLE 2. Side Effects on the Cavosurface and in the Subsurface Layer Viewed Under the Light Microscope

	Enamel (n = 20)			Dentine (n = 10)	
Group	−	+	Ø	−	+
1	19	0	1	10	0
2	20	0	0	9	1
3	20	0	0	10	0
4	20	0	0	10	0

In enamel, the marginal and occlusal level area was valued separately (n = 20/group) in dentine and the worst finding was recorded (n = 10/group). The results show no differences between the control and test groups. (−: no side effects; +: charring, cracking, debris; Ø: no results/no enamel left).

using a microgrinding system (EMS®). Finally, toluidine blue stain was applied without removal of the plastic embedding medium. To record the effects at the cavosurface, we systematically examined the ground cuts under 250 × magnification. The significance of the results was assessed with the Chi square test.

RESULTS

Histometric analysis showed that cavity depths were comparable in the different groups. The average extension of the laser cavities was 3.3 mm. The diameter of the diamond drilled cavities was slightly smaller than the corresponding diameter of the cavities in the laser group (Fig. 2).

Following conventional drilling no side effects were visible during light microscopic examination (Fig. 3 and Table 2). After laser preparation generally no signs of carbonisation and cracks could be detected in the enamel (Figs. 4 and 5). At one site no enamel was left after preparation of the marginal site (Table 2). In one specimen a small area of carbonisation at the dentinal surface could not be excluded. No significant differences were observed between the test and control groups.

The composite fillings exhibited a tight seal in all experimental groups including dentinal bonding (Table 3 and Fig. 6). Without the use of the Syntac-system (Group

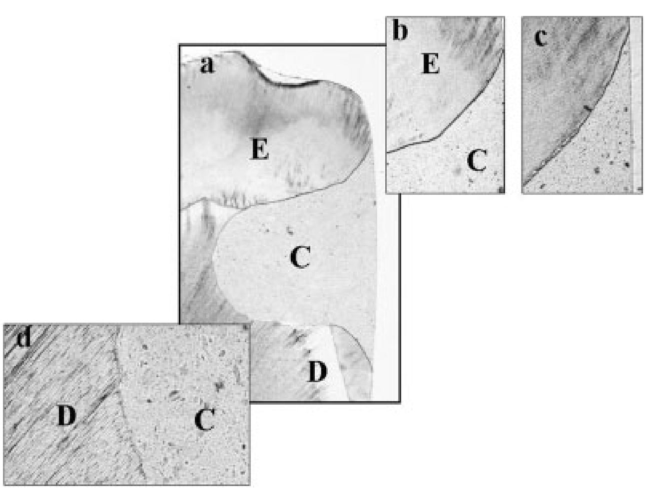

Fig. 3. Light micrographs of cross sections of a diamond drilled cavity (group 1). [E, enamel; D, dentine; C, composite resin]. **a**: Overview showing the outline of the cavity (× 16). **b**: Bevel of the coronal margin of the cavity (× 100): no side effects at the cavosurface. **c**: Detail from (b) (× 250): tight sealing. **d**: Detail of the pulpal wall, tight sealing in dentine (× 250).

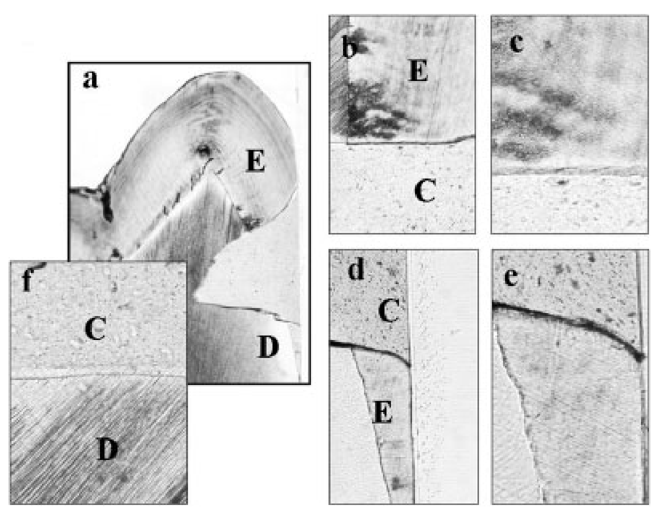

Fig. 4. Light micrographs of cross sections of a laser drilled cavity (group 4). **a**: Overview showing the outline of the cavity (× 16). **b**: Detail from the enamel–dentine junction of the coronal wall (× 250): no side effects. **c**: High power detail from (b) (× 400): no cracks, carbonisation or debris in enamel, tight sealing. **d**: Cervical margin of the cavity (× 100): no side effects. **e**: Detail of (d) (× 250): no gap at the cavity margin. **f**: Detail from the acial wall in dentine (× 400): good sealing, no side effects.

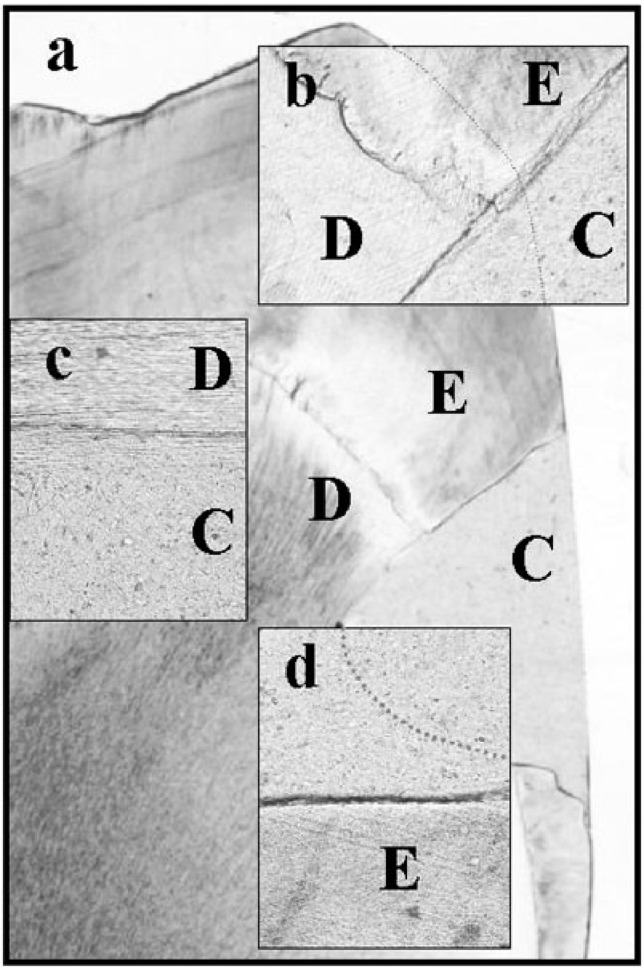

Fig. 5. Light micrographs of cross sections of a laser drilled cavity (group 3). **a**: Overview showing the outline of the cavity (× 16). **b**: Detail from the enamel-dentine junction of the coronal wall (× 250): no side effects. **c**: Detail from the acial wall in dentine (× 400): good sealing, no side effects. **d**: Cervical margin of the cavity (× 400): no gap at the cavity margin.

TABLE 3. Gap Formation Between the Cavosurface and the Restorative Material

Group (n = 10)	Incomplete resin adaptation
1	2
2	6
3	3
4	3

Leakage was recorded at a magnification of 250 × by light microscopy. The number of restorations affected by internal gaps increased when no dentine conditioning was performed ($P < 0.01$).

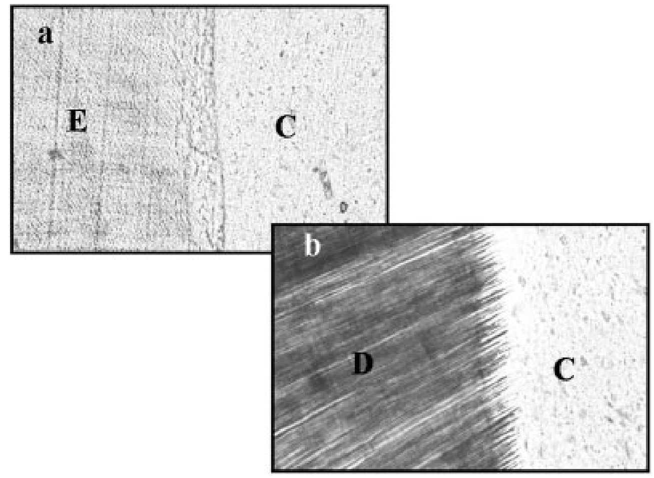

Fig. 6. High power micrographs from the resin/enamel (**a**) and resin/dentine (**b**) interface (× 400) of group 3: no laser induced side effects, tight sealing.

2) the adaptation of the resin to enamel and dentine was incomplete in many specimens (Fig. 7).

DISCUSSION

The results of this histological study point to a minimum of side effects when the superpulsed 9.6-μm CO_2 laser system is used for cavity preparation. The cavosurface of the laser-treated specimens was comparable to that of the specimens treated with conventional methods using diamond drills.

Each drilling instrument used in dentistry leaves characteristic fingerprints on the cavosurface. The enamel is the most sensitive tissue and the first to exhibit side effects. Overheating with rotary instruments or surgical

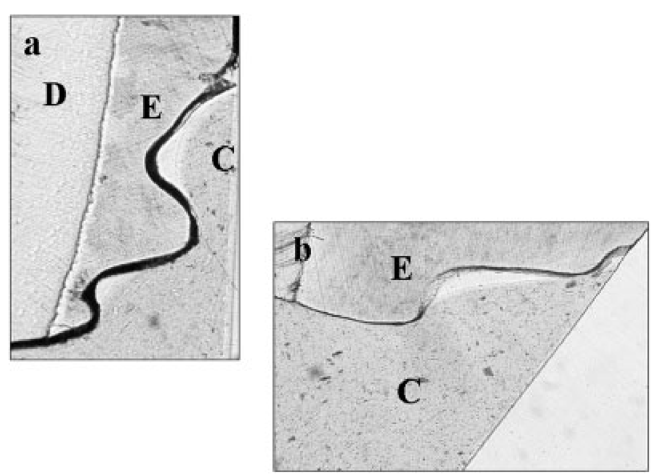

Fig. 7. Micrographs from marginal areas of laser cavities of group 2 (× 250): incomplete resin adaptation: without the use of acid and the bonding system, gaps appeared on the cavosurface.

cw CO_2 or Nd:YAG lasers results in charring, cracking and damage of the enamel structures [3,17]. Even thermomechanical ablation by Er:YAG lasers, which achieve the best results in dentine, causes a zone of damage in the subsurface enamel [17,18]. Consequently, these zones have to be removed with conventional drills to prevent gap formation [19,20]. Under the limitations of the recent study, the surface topography of superpulsed CO_2 laser drilled cavities is sufficient to bond resin based restorative materials. However, acid etching and dentine conditioning seem to be needed to prevent gap formation.

One of the major problems encountered in restorative dentistry is the lack of adhesion of dental restorative materials to mineralised dental tissues. The resulting gaps may influence the retention of the restorative material, increase secondary caries, or cause inflammatory reactions in the dental pulp [21]. Depending on the material used, the biological impact of the internal gap under restoration may be very different. Amalgam restorations, for example, usually result in considerable gaps between the restoration and the cavosurface, yet secondary caries and pulpal inflammation are minor problems. In resin restoration, however, micro-leakage seems to have clinically relevant effects (e.g., hypersensitivity, inflammatory reactions, bacterial pulp infection) [22]. Therefore, in resin restorations, a perfect and permanent adhesion to dental tissues is required [23]. Micro-leakage of composite resin restorations results from polymerisation shrinkage and the different coefficients of thermal expansion for composite resin and tooth structure [24].

The manufacturers of various dental lasers claim that these can be used as an alternative to acid etching for conditioning tooth surfaces for bonding [25]. Several studies have shown that tooth structure changes its surface properties following laser irradiation [26]. Goodman and Gwinnet [27] compared laser-etched enamel with acid-etched enamel and found that lasers created an enamel surface with cracks, pits, fractures, and craters that lacked sufficient porosity to permit resin penetration. Laser conditioning of the cavosurface raises the possibility that the roughened, irregular surface created by laser treatment may provide mechanical retention for dental restorative materials. However, this may not provide a surface as retentive as a surface treated with conventional acid etching [17,28]. Therefore, in laser cavity preparation it may be a real advantage to receive a cavosurface structure that can be conditioned according to conventional treatment. Under this premise, well-established composite resin systems can be used to seal and fill the cavities. The results of this study are encouraging in this respect. Further studies including SEM are required to prove adhesion at superpulsed CO_2 laser drilled cavities.

CONCLUSIONS

Histological examination revealed that the results obtained with laser preparation were comparable to those attained with conventional treating using diamond drills. Resin based restorative materials can be used to seal the cavities. The results indicate that the 9.6-μm CO_2 laser is a useful tool for cavity preparation. Resin based restorative materials can be used to seal the cavities.

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