ABSTRACT

Aim The aim of the study was to compare several cavity shapes after application using different handpieces and tips of Er:YAG laser.

Materials and methods Firstly, this in vitro investigation was performed on two upper molars. Their crowns were cut horizontally underneath the occlusal fissures in order to obtain a flat dentin surface. Afterwards, minimal cavities were prepared by using an Er:YAG laser device with a variety of handpieces and tips (Kavo KEY Laser Plus). All cavities were prepared using the following parameters: 250 mJ and 10 Hz during 30s, and were scanned using Micro-CT. Secondly, thirteen caries-free, human upper molars were prepared according to the same protocol. Five cavities were prepared on each tooth, using five different tips and the same laser settings as step one. The cavities’ depths were measured with a digital micrometer. The width and morphology were controlled under scanning electron microscope (SEM).

Results Noticeable differences in the dimensions of the cavities were observed, even if the same laser parameters were used for all preparations. Two main shapes were registered: triangle and rectangle.

Conclusion None of the cavities presented an adhesive configuration, rounded shape often found in hidden caries; they were straighter (rectangle) or focusing (triangle). For the moment, there is no ideal Er:YAG laser handpiece/tip in order to prepare conservative adhesive cavity.

Keywords Cavity preparation; Cavity shape; Er:YAG laser; Micro-computer tomography (Micro-CT); Minimally invasive dentistry.

Introduction

The Minimally Invasive Dentistry (MID) tends to stop the caries process and to restore lost tooth structure and function, increasing the healing potential of dental tissues. As they cannot regenerate, one of the most important aims is to preserve as much as possible the healthy hard tissue. A debate could be held about the different methods of cavity preparation. We decided to focus on laser cavity preparation that may represent one of the less invasive preparation methods available today. The first application of a laser for hard dental tissue ablation was described in 1964, by using the ruby laser (693.4 nm). In the following years, different other lasers with different wavelengths such as Nd:YAG (1.065 µm), CO₂ (9.6 µm) or Ho:YAG (2.12 µm) were also evaluated. The inconvenience of all those wavelengths is their low absorption in hard dental tissues, leading to low efficiency and increased temperature in dental pulp, microcracks and tissue carbonisation. In the 1980s, trying to limit tissue damage and to explore new ablation techniques, ultraviolet lasers and erbium lasers were developed. Er:YAG laser’s wavelength has a very high absorption in water and in hydroxyapatite, which makes it ideal for ablation of enamel and dentin [Iaria, 2008]. Moreover, a study concluded that erbium lasers (Er:YAG and Er, Cr:YSGG) are most efficient and, with the right parameters, their thermal side effects are small [De Moor and Delmé, 2009; Oelgiesser et al., 2003].

Laser-assisted cavity preparation follows the requirements of MID: the possibility to ablate only a small area of infected layer guarantees maximum conservation of the tooth structure; using the antibacterial property of the Er:YAG laser the affected layer is decontaminated [Sharon-Buller et al., 2003] and retains its remineralising potential; the lack of smear layer after vaporisation with laser assures a better retention of the composite resin to dentine and preparing the enamel surface with the Er:YAG laser before etching by applying the correct parameters may give a good marginal seal of the composite restoration [Komblit et al., 2009]. Moreover, the principle of fluorescence-controlled Er:YAG laser seems to be ideal for MID. Two studies in the current literature have tested the effectiveness of this method. One study has observed that cavities were smaller after caries removal with the non-contact laser compared to the bur and no significant differences were observed concerning the cavity size after excavation with the non-contact or the contact laser handpiece. Moreover, caries removal by a fluorescence-controlled Er:YAG laser using a threshold level of seven resulted in less dentine loss than preparations by a bur [Eberhard et al., 2005; Eberhard et al., 2008]. The second study concluded that treatment with a fluorescence-controlled Er:YAG laser removed the same level of caries as conventional bur treatment. Although more time consuming, laser
treatment seems to provide higher patient comfort [Dommisch et al., 2008]. As it has been demonstrated by the literature, Er:YAG laser seem to be appropriate for minimally invasive cavity preparations but there are different handpieces that can be used such as non-contact, sapphire tips with different shapes and fibres of different diameters. The purpose of this study was to evaluate the cavity shapes and micromorphology of cavity walls after application of Er:YAG laser light with the help of these different handpieces and tips. The null hypothesis was that there would be no difference between groups.

### Materials and methods

Intact, caries-free human upper molars were stored in 0.1% thymol solution at 4°C for the time between extraction and use for the test. After scaling and pumicing, the teeth were mounted on a custom made specimen holder using a cold-polymerising resin (Technovit 4071, Heraeus-Kulzer & Co, Wehrheim, Germany). The crowns were cut horizontally underneath the occlusal fissures in order to obtain a flat dentin surface perpendicular to the long axis of the tooth. For this purpose a slow speed saw (Isomet 11-1180, Evanston, Illinois, USA) under continuous water cooling was used. Afterwards,

<table>
<thead>
<tr>
<th>Cavity</th>
<th>Tip description</th>
<th>Arit</th>
<th>Laser parameters</th>
<th>Water spray</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>P2061 Sapphire 16/08 Length 26 mm Bottom: Dimension 1.1/0.5mm Shape rectangle flat</td>
<td>Cf 11</td>
<td>Energy: 250mJ Frequency: 10Hz Time: 30s</td>
<td>yes</td>
<td>2mm</td>
</tr>
<tr>
<td>1.2</td>
<td>P2061 Sapphire 12/08 Length 28 mm Bottom: Dimension 1.65/0.4mm Shape rectangle flat</td>
<td>Cf 11</td>
<td></td>
<td>yes</td>
<td>2mm</td>
</tr>
<tr>
<td>1.3</td>
<td>P2061 Sapphire 05/08 Length 28 mm Bottom: Dimension 1.65/0.5mm Shape Rectangle flat</td>
<td>Cf 11</td>
<td></td>
<td>yes</td>
<td>2mm</td>
</tr>
<tr>
<td>1.4</td>
<td>P2061 Sapphire 14/08 Diameter 1 mm Shape round rounded Length 26 mm</td>
<td>Cf 11</td>
<td></td>
<td>yes</td>
<td>2mm</td>
</tr>
<tr>
<td>1.5</td>
<td>P2060 Sapphire 128 Diameter 1.1 mm Shape round flat Length 26 mm</td>
<td>Cf 11</td>
<td></td>
<td>yes</td>
<td>2mm</td>
</tr>
<tr>
<td>1.6</td>
<td>P2063 Sapphire 276 Diameter 0.8 mm Shape round flat Length 14 mm</td>
<td>Cf 11</td>
<td></td>
<td>yes</td>
<td>Metal contact</td>
</tr>
<tr>
<td>1.7</td>
<td>P2063 Sapphire 378 Diameter 1 mm Shape round flat Length 14 mm</td>
<td>Cf 11</td>
<td></td>
<td>yes</td>
<td>Metal contact</td>
</tr>
<tr>
<td>2.2</td>
<td>P2062 Endodontic fiber n°2 Diameter 0.35mm</td>
<td>Cf 11</td>
<td>Yes (added in process)</td>
<td>&lt;1mm</td>
<td></td>
</tr>
<tr>
<td>2.3</td>
<td>P2061 Sapphire 16/08 Length 26 mm Bottom: Dimension 1.1/0.5mm Shape rectangle flat</td>
<td>Cf 11</td>
<td></td>
<td>yes</td>
<td>2mm</td>
</tr>
</tbody>
</table>

**TABLE 1** Description of the 13th Er:YAG laser tips and the parameters used for each cavity preparation.
minimal cavities were prepared by using an Er:YAG laser (Kavo KEY Laser 3+, KaVo, Biberach, Germany, Type: Key-Laser 1243, SN: 0000115, Upgrade-Kit III 3+, SN: 2009-1000012, Ref. 1.006.9613).

To find the ideal parameters to avoid dentine carbonization and be effective, we monitored in a pre-test different energies (mJ) and frequencies (Hz) and evaluated the resulting dentine micromorphology by means of SEM investigation. Based on these pre-tests, the selected parameters for all cavity preparations were: 250mJ and 10Hz during 30s, under continuous water spray. The laser tip was kept in the same position and angulation during the entire irradiation procedure, through the use of a boss clamp and retort stand.

On tooth no. 1, eight cavities were prepared using all the different sapphire tips of Key Laser 3+, one cavity for each tip (Fig. 1). For this procedure, the handpiece P2061 (SN: 1000022) was used with the near-contact sapphires 05/08, 12/08, 14/08 and 16/08 and the handpiece K2063 (SN: 07-1000054) with the contact-sapphires 276 and 378 (Table 1).

On tooth no. 2, two cavities were performed: one with the non-contact handpiece 2060 (SN: 1000016) at 6 mm distance from the tooth surface and a cavity with the handpiece E2062 (SN: 08-1001593) using endodontic fibres (N°2).

All cavities were scanned using Micro-CT (micro-computer tomography), a non-destructive method that uses x-rays to create cross-sections of the sample in order to recreate a virtual model of the tooth and the cavities without destroying the original model.

The acquisition of the scanner for each of the two samples needed 760 projections at 80 keV and a total time of acquisition of half an hour (Procon mini, Hannover, Germany), the reconstruction using the Feldkamp algorithm and GPU computation lead to 40 µm pixel resolution. Reconstruction, visualisation and data analysis were done using DigiCT software (Digisens, Le Bourget du Lac, France) (Fig. 2).

To complete the first study, thirteen caries-free human upper molars were stored in 0.1% thymol solution at 4°C for the time between extraction and use for the test. They were prepared according to the same protocol as the two previous teeth.

Afterwards, minimal cavities were prepared by using an Er:YAG laser (Kavo KEY Laser 3+, KaVo, Biberach, Germany, Type: Key-Laser 1243, SN: 0000115, Upgrade-Kit III 3+, SN: 2009-1000012, Ref. 1.006.9613). The parameters for all cavity preparations were: 250 mJ and 10 Hz during 30s, under continuous water spray. The laser tip was kept in the same position and angulation during the entire irradiation procedure, through the use of a boss clamp and retort stand.

On each of the thirteen teeth, five cavities were prepared using five different sapphire tips of Key Laser 3+, one cavity for each tip. For this procedure, the handpiece P2061 (SN: 1000022) was used with the near-contact sapphires 05/08, 14/08 and the handpiece K2063 (SN: 07-1000054) with the contact-sapphires 276 and then the near-contact handpiece 2060 (SN: 1000016) at 6 mm distance from the tooth surface.

The cavities’ depths were measured with a digital micrometer with a resolution of 1 µm. (Sylvac µS233, Serial-No: 724556, Sylvac SA, Ch. du Closalet 16, 1023 Crissier, Switzerland) [George and Walsh, 2007].

To enable the measurement of depth when the cavity diameter is less than 1 mm wide, an endodontic file, diameter 10 has been fixed on the tip of micrometer. The endodontic file was placed in the deepest part of each cavity in several places trying to find the highest value. The micrometer was calibrated before each measurement by setting it to zero at the edge of each cavity. In addition, the width of each cavity was measured under the scanning electron microscope (SEM) and the surface morphology of all the preparations were controlled by SEM (Sylvac µS233, Serial-No:724556, Sylvac SA, Ch. du Closalet 16, 1023 Crissier, Switzerland) with a variety of magnifications.

**Results**

Similar to cavity preparation with burs, the use of
different Er:YAG laser tips and handpieces significantly influenced the macro-morphology of dentin cavities. Moreover differences in the dimensions of the cavities were observed, even if the same laser parameters were used for all preparations. Table 2 summarises the shape and the dimension of each laser cavity registered with the Micro-CT method.

The average laser cavity depth was 1.2 mm. An important exception were the cavity 2.1 and 2.2, prepared with the handpiece E2062 (SN: 08-1001593) using endodontic fibre N°2 and the non-contact handpiece 2060 (SN: 1000016) respectively. These two tips, without changing the Er:YAG parameters, gave the deepest cavities (2 mm).

On the horizontal section of the teeth the top of each cavity corresponded to the shape of the laser tip used (Fig. 1). As the tips 05/08, 12/08, 16/08 were rectangular, the corresponding cavities 1.1, 1.2 and 1.3 had rectangular shapes on their surface. All the cavities that corresponded to round sapphires, endodontic fibres and to the non-contact handpiece had a round shape in horizontal section. For tooth no. 2, all the cavities could not be exploited because of the remaining enamel ranges. Nevertheless, the experimental conditions of this tooth confirmed that the section of the cavity corresponds to the shape of the sapphire and that the endodontic fibres are responsible for deep cavities. Furthermore, this tooth has a control cavity 2.3 (cavity 3 on tooth 2) that corresponds to the cavity 1.1 (cavity 1 on tooth 1) on table 2. This control cavity shows us, that despite the changes of dentin between teeth N°1 and N°2, measurement are very close, therefore comparable. For the thirteen teeth we also noticed a relationship between the shape of the tip and the shape of the cavity.

<table>
<thead>
<tr>
<th>CAVITY</th>
<th>ARIT</th>
<th>DIAMETER (MM)</th>
<th>DEPTH (MM)</th>
<th>ANGULATION (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td></td>
<td>1</td>
<td>1.2</td>
<td>70</td>
</tr>
<tr>
<td>1.2</td>
<td></td>
<td>1.8</td>
<td>1.3</td>
<td>75</td>
</tr>
<tr>
<td>1.3</td>
<td>*</td>
<td>1*</td>
<td>1.3*</td>
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<td>1.2*</td>
<td>30</td>
</tr>
<tr>
<td>1.5</td>
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<td>0.7*</td>
<td>1.5*</td>
<td>50</td>
</tr>
<tr>
<td>1.6</td>
<td></td>
<td>0.8*</td>
<td>1.6*</td>
<td>25</td>
</tr>
<tr>
<td>1.7</td>
<td></td>
<td>1</td>
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<tr>
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<td></td>
<td>0.4</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>2.2</td>
<td></td>
<td>0.7*</td>
<td>2.1*</td>
<td>12</td>
</tr>
<tr>
<td>2.3</td>
<td></td>
<td>0.9</td>
<td>1.1</td>
<td>60</td>
</tr>
</tbody>
</table>

**Table 2** Shapes et dimensions of each laser cavity registered with the micro-CT method.
In the vertical section, two main shapes were registered: triangle and rectangle (Table 2). The rectangular shape was delivered by the sapphires surrounded by metal (276 and 378), the endodontic fibre and the non-contact handpiece 2060, while all the other sapphires gave triangular cavity shapes, under different angulations. A particular shape was registered for the cavity 1.4 prepared with the near-contact rounded top sapphire 14/08. This cavity presented an irregular bottom surface, higher in the centre (0.8 mm) than at the margins (1.2 mm) (Table 2).

Discussion

There is a general consensus in the literature that Er:YAG is one the most suited types of laser for cavity preparation [De Moor and Delmé, 2009]. Its advantages are based on its efficiency, especially in dentin and carious lesions [Furtando Messias et al. 2006], its safety for the pulpal tissue while working under sufficient water cooling [Firoozmand et al., 2008] as well as its sterilisation capacity at the surface of the cavity [Schoop et al., 2004]. In addition, almost painless preparation may be possible, allowing to work without local anaesthesia in many instances [Keller et al., 1998; Komblit et al., 2008]. Moreover, Er:YAG laser increases the remineralising potential of dental tissues and provides optimal enamel and dentin surfaces for the adhesion of composite resins, if the parameters for cavity preparation and finishing are well respected [Komblit et al., 2008]. Finally, compared to others, Er:YAG laser has a good cutting effect on dental hard tissue without any side effect [Harashima et al., 2005]. From a clinical point of view, a study comparing Er:YAG laser to bur preparation found out that 83% of the patients described the laser treatment as more comfortable than bur treatment, this and other studies having demonstrated a great acceptance of Er:YAG laser by the patients [Hibst and Keller, 1989; Hibst, 2002].

Beside all these advantages, what attracted our attention for this in vitro study was the possibility to obtain minimally invasive cavities [Banerjee, 2013]. Indeed we can compare those conservative cavity dimensions to the smallest drills available with a diameter of 0.3-0.6 mm.

To measure the cavities in 3D, the Micro-CT technique was used. The CT technical principle is well known (Cormack & Hounsfield, Nobel prize 79) due to its medical application. Micro-CT was developed in the 90’s for material and biologic samples analysis. Very similar to medical CT the main differences are resolution of the CT and foot print of the system. The limitations for high resolution (typically 10 µm to 100 µm range compared to the 0.5 mm for a medical CT) are the size of the sample linked to physical law, where the higher the magnification the smaller the sample is, besides the need of important X ray doses for high resolution. This is why nano- and micro-CT is generally dedicated to in vitro analysis. The Micro-CT was well suitable to evaluate the experimental question of this study as it allowed for a non-destructive three-dimensional quantitative analysis of the cavities with a high accuracy.

It was interesting to notice that for the same laser parameters (250 mJ, 10 Hz) and the same exposure time (30s), different shapes and different dimensions of the dental cavities were registered. The only variables were the type of the laser tip and the distance between the tip and the dentin surface, according to manufacturer’s instruction.

For the seven sapphires used, the distance was kept at less than 2 mm, even for the “contact” ones. For these last ones the contact with the tooth is made through a metal housing, keeping a constant 2 mm distance between the top of the sapphire and the tooth’s surface. The corresponding cavities of these seven sapphires had comparable depths, between 1.1 and 1.6 mm. What was different between these cavities was their shape, on horizontal and vertical sections, corresponding to the shape of the laser tip. Also, the entry diameter of these cavities corresponded to the diameter of the sapphire used. In the horizontal section, cavities 1.1, 1.2 and 1.3 presented on top the same rectangular shape as the corresponding sapphires 05/08, 12/08, 16/08 and at the bottom a sharp edge, which might be explained by the focus of the laser energy. In vertical section, the shape of these cavities was triangular, with the entry diameters and angulations proportional to the diameter of each tip. Cavity 1.4 prepared with the sapphire 14/08 had a particular shape, different from all the others: rounded entrance but irregular bottom surface, with smaller depth of 0.8 mm measured in its centre and the margins at 1.2 mm deep from the surface. It might be speculated that this Er:YAG laser tip, which is the only one used in the present study with a perfect rounded top, irradiates with an angle, dispersed the laser light from the centre of the sapphire. Following the same principle, the cavity 1.5 had the same circular shape in the horizontal section as the corresponding sapphire 128, the same entrance diameter (1.1 mm) and a triangular shape in the vertical section due to the focus of the laser light.

The cavities 1.6 and 1.7, obtained with the contact-sapphires 276 and 378 surrounded by metal, have generally the same characteristics: circular horizontal diameter of 1.1 mm and 0.8 mm, corresponding to the shape and the diameter of the sapphire. The only difference consisted in the vertical shape of the two cavities, which was not a triangle as for the other sapphires, but a rectangle. This was probably due to the metal frame that reflects the light from the sapphire and keeps the irradiation almost at the same diameter until the bottom of the cavities.

The big exceptions from the rule, in terms of distance between tip and dental structure, shape and depth of the prepared cavities, were the two non-sapphire laser tips: the endodontic fibre and the non-contact
handpiece that uses no tip. The endodontic fibre was used almost in contact with the dentin, but without touching it. Actually, this type of laser tip had not initially been conceived for cavity preparation, but after preliminary tests we observed its effect on dental hard tissues and we decided to include it in the present study. The diameter of the cavity (0.4 mm) corresponds again to the diameter of the fibre (0.35 mm), but the vertical shape, as for the cavity prepared with the non-contact handpiece, is narrow and rectangular (12° of angulation).

The non-contact handpiece was kept at a distance of 6 mm from the dentin surface, distance found optimal during the preliminary tests. In these conditions, the cavity obtained had a diameter of 0.7 mm.

The two last cavities were also the deepest from the nine cavities of the study. The concentration of the laser energy on a very small area (0.4 mm and 0.7 mm respectively) could explain this important depth (2 mm).

In general, the following relations were observed:

- The shape and diameter of Er:YAG laser prepared cavities depend on the sapphire's shape and diameter.
- In general, sapphire tips have the tendency to focus the light at a certain distance from the tip, delivering cavities with triangular shape in vertical section. Exception are tips with special shape or construction: rounded top of the sapphire, metal frame around the sapphire and the non-sapphire tips.
- The depth of the laser cavities under identical laser parameters and exposure time was in mean 1.2 mm, exception being cavities 22 and 23 with 2 mm depth, because of the higher energy density due to the laser concentration of energy on a very small surface of 0.4 or 0.7 mm in diameter, respectively.

It is impossible to compare the present results to the existing literature as according to the knowledge of the authors this is the first study on cavity morphology with different Er:YAG laser handpieces and tips. It shows that cavity shape and size depend not only on the laser parameters, as reported in previous studies [Delmé et al., 2006] but equally on the type of the handpiece/tip used.

Conclusion

The most important aim of Minimally Invasive Dentistry is to preserve a maximum of dental hard tissue. Er:YAG laser may thus represent a good cavity preparation method for conservative treatment. Indeed, cavity sizes registered in this study were between 0.4 and 1.8 mm in diameter. Moreover the 30 seconds, 250mJ and 10Hz used for cavity preparation seemed to be reasonable and efficient for clinical application. Unfortunately, none of the cavity presented an adhesive, rounded shape often found in hidden cavities; they were more straight (rectangle) and focusing (triangle). It seems that for the moment there is no ideal Er:YAG laser tip to prepare conservative adhesive cavity. In the field of classical box shaped geometrical preparations laser can hardly compete with bur, which are not only much cheaper but also faster. On the other hand, one of the disadvantages of bur treatment is that it needs a direct access to the decay and a clinical control of the entire lesion's ablation. It will be interesting to develop a sapphire that could irradiate not only on his main axis but also perpendicularly or with a 45° angulation to better fit the shape of a hidden cavities lesion.

References