Composite removal by means of erbium, chromium:yttrium-scandium-gallium-garnet laser compared with rotary instruments

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ABSTRACT

Background. Complete removal of existing composite restorations without unnecessary removal of tooth structure is challenging. The authors compared the amount of tooth structure removed and composite remaining in Class III preparations when using an erbium laser or a rotary instrument.

Methods. Mesiolingual and distolingual preparations were prepared in 14 extracted anterior teeth, restored with shade-matched composite, finished, and polished. One restoration was removed with an erbium, chromium:yttrium-scandium-gallium-garnet laser and the other with a rotary instrument (handpiece and carbide burs). Gypsum models made from vinyl polysiloxane impressions of the preparation and removal stages were scanned. The 2 scans were precisely aligned to calculate the amount of tooth structure removed and residual composite, which were statistically compared (t test) between the bur and laser groups.

Results. Rotary instruments removed significantly more tooth structure than the laser in terms of mean depth ($P = .0017$) but not maximum depth ($P = .0762$). Although mean depth of tooth loss was smaller in the laser group, the area of tooth loss was significantly larger ($P = .0004$) because the rotary instrumentation left significantly more composite than the laser in terms of volume ($P = .0104$), mean depth ($P = .0375$), maximum depth ($P = .0318$), and area ($P = .0056$).

Conclusions and Practical Implications. The erbium, chromium:yttrium-scandium-gallium-garnet laser was more selective in removing existing composite restorations than a rotary instrument because it removed less tooth structure and left behind less composite. Unintentional loss of tooth structure and unnoticeable residual composite are inevitable when removing existing composites. Erbium lasers are alternative means of composite removal that may be more selective than a rotary instrument.

Key Words. Bur; composite; laser; restoration removal; tooth structure.

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A survey of dental services conducted by the American Dental Association from 2005 through 2006 estimated that more than 76 million composite restorations were placed in the United States in 1 year.[1] Considering the annual failure rate of 1% through 3% for posterior restorations[2] and up to 4% for anterior restorations,[3] replacing composite restorations is a substantial part of a dental practice. When existing composite restorations require replacement, clinicians usually remove all of the composite to check for the presence of any infected dentin under the existing restoration and to create fresh tooth structure suitable for bonding.[4] This "if in doubt, take it out" approach could result in unnecessary removal of sound tooth structure and larger restorations.[5] For the current generation of composite materials with excellent shade matching and durable bonding, removal of these restorations with rotary instruments is more challenging than ever. Clinicians who use a more minimally invasive philosophy and technique for existing restoration removal may leave behind composite, either intentionally or unnoticed.

Laser instruments, which have been used for tooth preparation and caries removal, may offer a better method for removal of composite restorations.[6-11] The earliest trials, by Goldman and colleagues,[12,13] used a ruby laser on teeth and failed miserably, causing cracks and melting of enamel in the best of cases and complete charring in the worst. When different wavelengths were developed for hard tissues, that is, erbium lasers, dentists finally had a device that could be used to prepare all preparation classes. The erbium laser was deemed safe for use in both adults and children and actually caused a cooling effect in the pulpal tissues.[14-16] The ultrashort pulsing combined with an aerosolized water spray provided this thermal safety. As the technology continues to develop, power output can be controlled with such precision that hard-tissue ablation can be surprisingly precise.[17,18] In a case study, Gregory and colleagues[10] reported using an erbium, chromium:yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser (WaterLase, Biolase) to remove deep carious lesions without pulpal exposure whereas caries removal with a conventional high-speed rotary instrument resulted in pulpal exposure in a comparable contralateral lesion.

Over the years, research groups have reported the development or use of short, microsecond-pulsed carbon dioxide (CO_2) and erbium lasers for composite removal with varying degrees of success.[6-9,11] CO_2 lasers operate at a wavelength that ablates composite resin at a distinctly higher rate than enamel.[6,9,11] However, removal of composite on dentin was not included. The ablation of composite resin occurs as a result of a thermomechanical event, with the laser's photonic energy being absorbed by water and other fillers and ingredients contained within the restorative material. Initially, no water exists within the composite resin; however, it has been shown that water sorption may occur over time.[19] Because of this and the fact that there is little water contained within the crystalline matrix of enamel, erbium lasers preferentially remove composite rather than enamel, while being less selective in dentin due to a higher water content.[7] Correa-Afonso and colleagues[8] suggested that erbium lasers may leave molten composite along carious lesion walls, which cannot be removed easily by means of laser ablation. Owing to the melting process noted in their study, the remaining material absorbers were missing. Some erbium laser operators have observed clinically that a thin remaining layer of composite was often easily dislodged. This observation may be related to a photoacoustic effect, which creates a shock wave that reduces the bond of the remaining composite to the tooth structure.[18] If this behavior is confirmed, composite removal with a laser will support the preservation of sound tooth structure. We hypothesized that an erbium laser could precisely remove existing composite restorations. The objectives of our study were to compare the amount of tooth structure removed and composite remaining in Class III preparations after removal of composite restorations with an erbium dental laser or by means of a standard clinical procedure using rotary instruments (high-speed handpiece and carbide burs).

METHODS

Tooth preparation and 3-dimensional (3D) scanning

Fourteen extracted caries-free anterior teeth (institutional review board approval 17-05324-NHSR), stored in 10% buffered formalin acetate, were cleaned with a pumice slurry and mounted in acrylic resin. During the experiment, the teeth were kept hydrated in deionized water at all times. Two experienced clinicians (J.A.R., C.R.T.) prepared mesiolingual and distolingual Class III preparations (Figure 1A), using a no. 6 round carbide bur with a high-speed handpiece under copious amount of water. Preparation dimensions were prescribed as 3 millimeters (incisogingival), 2 mm (mesiodistal), and 2.5 mm (facial extension). The preparation geometry was that of a "C" shape with rounded internal walls without undercuts. Enamel margins were beveled (0.5 mm wide) using the same carbide bur. Each clinician prepared 7 teeth. A researcher (D.T.) obtained impressions of the prepared teeth, using vinyl polysiloxane (Express Light Body lot N669071, 3M ESPE), and made dental stone models (GC Fujirock EP Premium PW, GC Europe) from the impressions. The tooth models with preparations were scanned with a 3D optical scanner (COMETxS, Steinbichler Optotechnik). The optical scanner precisely digitized the surface morphology from 8 directions, collecting points every 60 micrometers (resolution) with 5-μm accuracy in 3 dimensions. The white-light optical scanner could not measure reflective surfaces such as dentin and unetched enamel. This limitation was overcome by scanning the stone replicas.

Composite restoration, artificial aging, and composite removal

The clinicians (J.A.R., C.R.T.) used a total-etch bonding technique, in accordance with the manufacturer's instructions: enamel and dentin surfaces were etched for 15 seconds with phosphoric acid gel (Scotchbond universal etchant, 3M ESPE), rinsed thoroughly with water, and gently

ABBREVIATION KEY

CO_2: Carbon dioxide.
Er,Cr:YSGG: Erbium, chromium: yttrium-scandium-gallium-garnet.
3D: 3-dimensional.

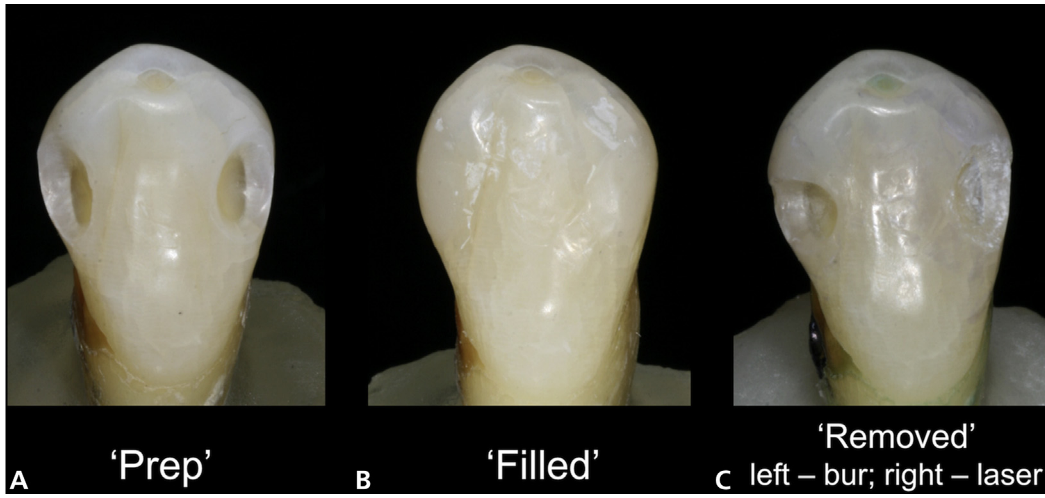

Figure 1. A. Mesiolingual and distolingual preparations were restored with shade-matched composite and then contoured and polished (**B**). **C**. One restoration (left) was then removed with a rotary instrument and the other restoration (right) was removed with an erbium laser.

air-dried with an air syringe to remove excess water. Then, while keeping the surface moist, the clinicians applied an air-thinned coating of Scotchbond universal adhesive (3M ESPE) followed by light-curing for 10 seconds (1,234 milliwatts per square centimeter) (Demi Ultra LED curing light, Kerr). The preparation were restored with shade-matched composite (TPH Spectra ST, Dentsply Caulk) in 2 increments, and each increment was light-cured for 20 seconds. The restorations were finished to an ideal contour (Figure 1B) using a 12-bladed 7404 carbide finishing bur, and polished with a PoGo polishing point (Dentsply Caulk). Each clinician restored the 7 teeth they prepared. The restored teeth were artificially aged by subjecting them to 5,000 cycles of temperature change alternating between hot (55°C) and cold (5°C) water with an immersion time of 30 seconds.[20] After thermocycling, 2 clinicians randomly removed 1 of the 2 composite restorations (Figure 1C) from the teeth that were restored by a different clinician (C.R.T., J.A.R.) (that is, the operator did not know the shape or the exact dimensions of the original preparation), using a rotary instrument (high-speed handpiece and round carbide bur nos. 4 and 6) under a copious amount of water, with the aid of a finishing carbide bur in some instances. Each clinician thus removed only 1 restoration from each of the 7 teeth. A third clinician (C.J.W.), who is experienced in erbium laser use, removed from all 14 teeth the second composite restoration (Figure 1C) using an Er,Cr:YSGG laser with a 600-μm-diameter, 6-mm-long fiber tip, 150 millijoules per pulse, 15 hertz (2.25 watts), 50% air, 80% water (Waterlase iPlus, Biolase). The clinician who operated the erbium laser did not know the exact dimensions or shape of the preparations. All 3 clinicians were instructed not to create undercuts. They used magnification loupes and were allowed to use a spoon excavator to remove loose composite remnants. They also periodically used a dental explorer to evaluate the removal of composite. The researcher recorded total time used for composite removal, excluding the explorer evaluation time, for both methods.

Final scan and data analysis

Vinyl polysiloxane impressions of the teeth were obtained after composite removal to create dental stone models for 3D optical scanning. Cumulus software[21] was used to align the scanned models with removed composite with the corresponding tooth preparation models by minimizing the root-mean square differences between selected unchanged tooth surfaces (Figure 2A). After this process, dimensional changes between the 2 scans were visualized with contour maps, using a linear color scale (Figure 2B). Two types of dimensional changes were identified:

- surface loss, representing additional tooth structure removal;
- surface gain, representing composite remaining.

Areas of surface loss or surface gain were separately selected, using the contour maps (Figure 2B,C). Subsequently, dimensional changes (volume, mean depth or thickness, maximum depth or thickness, and area) of removed tooth structure and residual composite were calculated.

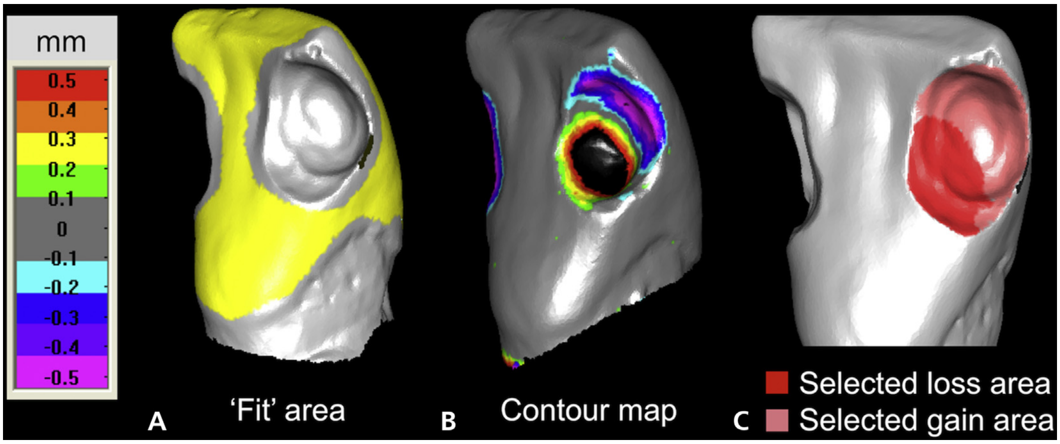

Figure 2. A. The 3-dimensional scan of the original preparations and the scan after composite removal were aligned using the unchanged tooth surface as the fitting area (yellow). **B**. The amounts of tooth structure loss and remaining composite are shown with a color contour map: green, yellow, and red represent tooth structure loss, and blue, purple, and pink represent remaining composite. Black areas indicate that the change was more than 0.5 millimeters, and gray indicates areas with less than 0.1 millimeter change. **C**. The image on the right shows how areas of surface loss and surface gain were separated to quantify the amount of tooth structure loss and composite remaining.

Statistical differences between bur and laser removal were determined by *t* test (Microsoft Excel, Microsoft).

RESULTS

The table shows the amount of tooth structure loss and remaining composite (volume, mean depth or thickness, maximum depth or thickness, and area) after composite removal with a rotary instrument (handpiece with carbide bur) or laser. The table also shows the 95% confidence intervals and *P* values. Rotary instrumentation left significantly more composite than the laser in terms of volume, average thickness, maximum thickness, and area ($P = .006$-.04). The rotary instrument removed significantly more tooth structure than the laser in terms of mean depth ($P = .0017$) but not volume ($P = .2064$) or maximum depth ($P = .0762$). Volume is the product of depth and area. Some teeth in the rotary instrument group had less area of tooth structure removed because the area of remaining composite was larger. However, because of the generally deeper cuts in the rotary instrument group, volume loss was also greater. The fact that less composite remained in the laser group explains why the laser group had a significantly larger area of tooth loss ($P = .0004$). Figure 3 shows the color contour maps of 2 teeth after composite removal with the rotary instrument and laser, showing areas with tooth structure loss (green, yellow, orange, and red) and residual composite (blue, purple, and pink).

The time (mean [standard deviation]) needed for composite removal when using a rotary instrument was 143.71 (32.68) seconds, whereas restoration removal with the laser took 119.86 (62.13) seconds. These values were not significantly different ($P = .2325$). The 95% confidence intervals were 126.59 to 160.83 seconds for the rotary instrument and 87.31 to 152.40 seconds for the laser.

DISCUSSION

Replacing composite restorations because of defective margins or recurrent caries is a common procedure in a dental practice. When removing composite, clinicians may inadvertently remove tooth structure surrounding the restoration while trying to ensure complete removal of the material or may unintentionally leave composite behind in challenging areas. When using an erbium laser to remove an existing composite restoration, operators have often observed that the last thin layer of composite is easily dislodged. If that is the case, composite removal should be more precise.

The result of our study partially supported this hypothesis. Our results indicate that the Er,Cr:YSGG laser removed significantly less tooth structure and left fewer composite remnants than the rotary instrument. Yet, some tooth structure was still lost (average depth of 10 μm for the laser group and 24 μm for the rotary instrument group) and not all composite was removed (average

Table. Amount of tooth structure loss and residual composite (volume, mean depth or thickness, maximum depth or thickness, and area) after composite removal with a rotary instrument (handpiece with carbide bur) or Er,Cr:YSGG laser.

MEASUREMENT	VOLUME (CUBIC MILLIMETER)		MEAN DEPTH OR THICKNESS (mm)		MAXIMUM DEPTH OR THICKNESS (mm)		AREA (SQUARE mm)	
	Bur	**Laser**	**Bur**	**Laser**	**Bur**	**Laser**	**Bur**	**Laser**
Tooth Structure Loss								
Mean (standard deviation)	1.57 (1.23)	1.13 (0.65)	0.24 (0.09)	0.10 (0.06)	0.54 (0.18)	0.40 (0.18)	6.16 (4.12)	11.46 (3.16)
95% Confidence interval	0.92 to 2.21	0.79 to 1.47	0.19 to 0.29	0.07 to 0.14	0.45 to 0.63	0.30 to 0.49	4.00 to 8.32	9.80 to 13.11
P value	.2064		.0017		.0762		.0004	
Residual Composite								
Mean (standard deviation)	1.37 (1.36)	0.23 (0.29)	0.21 (0.12)	0.11 (0.11)	0.52 (0.31)	0.28 (0.27)	5.81 (4.68)	1.58 (1.41)
95% Confidence interval	0.66 to 2.08	0.08 to 0.39	0.14 to 0.27	0.05 to 0.17	0.36 to 0.68	0.14 to 0.42	3.35 to 8.26	0.84 to 2.32
P value	.0104		.0376		.0318		.0056	

thickness was 11 μm for the laser group and 21 μm for the rotary instrument group). de F.Z. Lizarelli and colleagues[7] reported that an erbium:yttrium-aluminum-garnet laser ablated composite 5 through 10 times faster than enamel, with dentin more vulnerable to removal than composite. In our study, we also observed more tooth structure loss in dentin than in enamel (Figure 3), which is consistent with the previously reported results. Jang and colleagues[11] reported an average depth of enamel loss of 18 μm when using a CO_2 laser to remove composite from small occlusal preparations. We found tooth structure loss (combination of enamel and dentin) of 11 μm after composite removal from moderate size Class III restorations when using an erbium laser.

Multiple processes play out during the operation of a free-running pulsed erbium laser. Hard-tissue ablation is the result of a combination of photonic phenomena, including photothermal and photoacoustic effects.[14,15,18] Correa-Afonso and colleagues[8] suggested that the mechanism of composite ablation is explosive vaporization when fast-melting material expands followed by hydrodynamic ejection. They found incomplete removal of composite because the material vaporized quickly in the center and the pressure drove out the surrounding melt, suggesting that a high laser repetition rate is more effective in composite removal but that it may heat up the surrounding materials.[8] To avoid such complications, preliminary tests were performed to identify the ablation threshold and most appropriate parameters for the laser settings during composite removal. We used those settings in our study. Some studies reported that Er,Cr:YSGG lasers did not change or even decreased pulpal temperature because of the short (microsecond) pulses and the presence of air-water vapor during operation.[5,15] The lower average power used in our study was thus unlikely to increase the pulpal temperature. Once most of the composite is ablated from an existing restoration, the photoacoustic effect creates a vibration between the composite material and the tooth surface that may result in dislodging the remaining layer of composite; this is often observed clinically by erbium laser operators (CJ Walinski, DDS, written communication, April 2017). The longer a composite restoration has been in the mouth or the more defective the restoration is, the more dramatic this effect appears.

We observed that the laser-cut interfaces were relatively rough and chalky (Figure 1C) with microirregularities (Figure 3). These microirregularities are characteristic of erbium laser ablation and are associated with the microexplosive effects.[22] These differences in laser ablation between tooth structure and composite resin are visible clinically, making it slightly easier to distinguish between target types. Scanning electron micrographs have shown that tooth surface that has been ablated with an erbium laser has no smear layer and has improved bond strengths compared with traditional handpiece-cut and acid-etched surfaces.[8,22-24] It should be noted that overetching as a result of the absence of a smear layer and alteration of enamel morphology from laser ablation could compromise the bonding efficacy of some adhesive systems.[25,26]

Our study simulated clinical aging by thermocycling the restored teeth. Over time, composite restorations eventually become deficient and are likely to be replaced owing to secondary caries or fracture or because of esthetic demands.[2,3] Cyclic temperature changes in the oral cavity caused

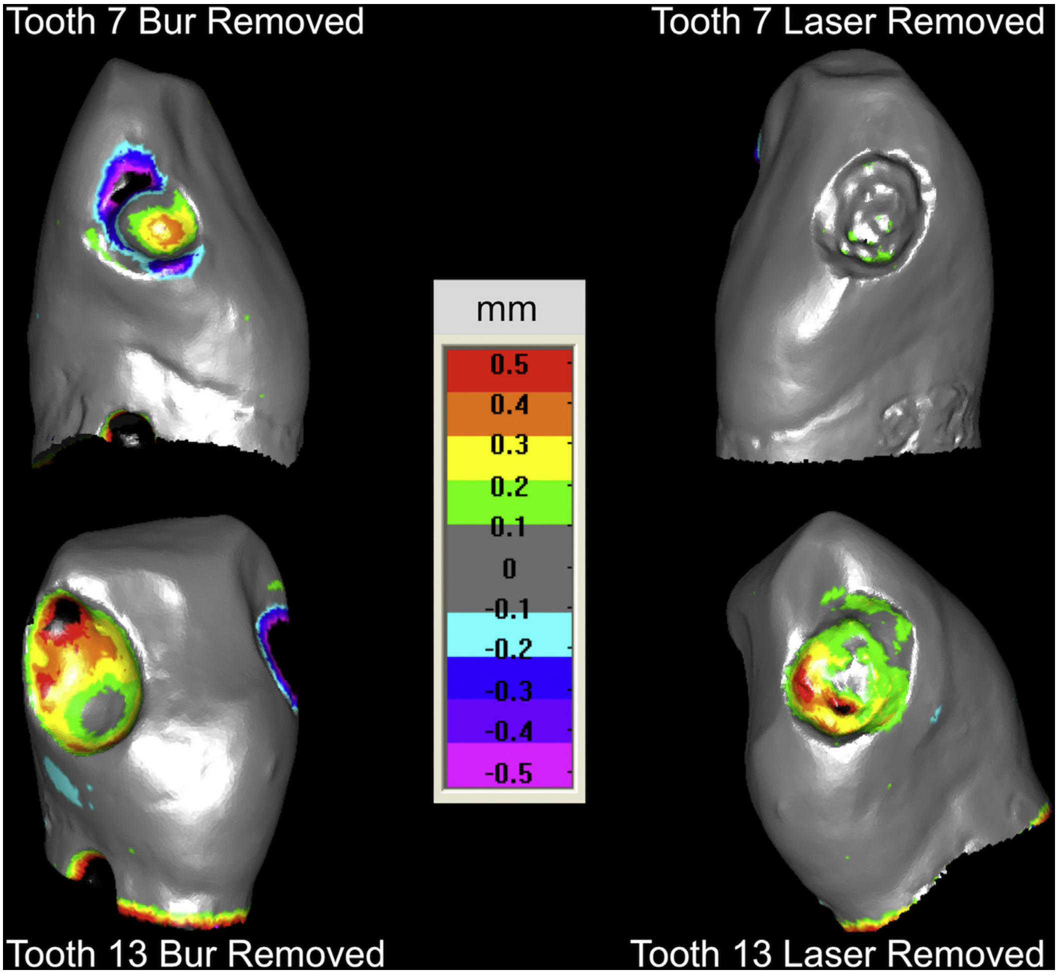

Figure 3. Contour maps show areas of remaining composite surrounding a preparation of bur-removed composite and a relatively clean preparation of laser-removed composite in 1 tooth. In the black areas, the change was more than 0.5 millimeters, and the change was less than 0.1 mm in gray areas. Another tooth shows areas of tooth loss in both bur-removed and laser-removed caries.

by eating or drinking food that is hot or cold induce varying stresses at the composite-tooth interface owing to the differences in thermal expansion and contraction between the composite and tooth structure.[27] This thermal fatigue is thought to challenge the bonded interface and create gaps, which allow oral fluid between the restoration and tooth structure. Although the extent of the effect of thermocycling on bond integrity is arguable,[27,28] water absorption during the thermocycling is another aging mechanism that can influence the durability of an interface.[27] In addition, resin-based restorative materials absorb water.[19] This aspect is important in our study because the presence of water along the interface or absorbed by the composite could enhance the effectiveness of erbium laser ablation.[15] We thermocycled the restored teeth for 5,000 cycles, which is thought to correspond to 6 months of clinical function.[29] Clinical studies showed that survival rates of large composite restorations were more than 70% at 12.0 years, and were 7.8 years for extensive composite restorations.[30,31] We expect more interfacial deterioration and higher water absorption in composite restorations that have had longer service times. This could enhance the photoacoustic effect and the selectivity of an erbium laser as previously discussed. Nonetheless, the ablation efficiency may be different among various composite materials because of differences in ablation thresholds and degree of laser absorption.

Shade-matched composite restorations are challenging to remove completely. In our study, we selected composite shades to match the original tooth surface to replicate clinical practice. Operators in both the laser and rotary instrument groups left some composite behind unintentionally. Clinically, there are instances when remaining composite is intentionally left, such as to reduce the risk of pulpal complications.[5] Our objective was to evaluate differences in the amount of tooth structure removed and composite remaining between the bur and laser techniques. Treatment of residual composite was not the objective of this investigation.

To our knowledge, our study is the first to measure changes in preparation dimension by simulating clinical practice in terms of preparation size and shape, restorative procedures, and composite removal steps. The technique used to measure changes in dimensions is well established.[32-34] The accuracy and precision of dental stone models made from vinyl polysiloxane impressions were reported to be 0.024 mm with the upper and lower limits of the precision being 0.002 mm.[35] We designed the study protocol so that laser operators and rotary instrument operators did not know the original size and shape of the preparation. The operators were aware that the preparations did not have undercuts. This requirement was necessary because the optical scanner used in our study could not scan an undercut area. The lack of undercut could be an advantage to both the bur and laser groups because the operators might remove more tooth structure if an undercut was present. The operators were aware of the objective of our study, and they were asked to remove the composite restorations as precisely as they would in their clinical practices. Because both the amount of tooth structure removed and composite remaining were being measured, the operators understood that intentionally leaving composite or deliberate overpreparation would be obvious. In addition, because the clinical operators in our study each had more than 20 years of experience, the precision of composite removal likely depended not only on instrument characteristics but also on personal judgment. In clinical practice, personal judgment and skills will also affect a practitioner's efficacy in preservation of tooth structure. Our study suggests that using an Er,Cr:YSGG laser to remove existing composite restorations may be an advantage in reducing both tooth structure loss and composite remnants compared with standard rotary instruments.

CONCLUSIONS

When removing existing composite restorations, an Er,Cr:YSGG laser saved more tooth structure than did a rotary instrument. In addition, fewer composite remnants were left in the preparation when using the Er,Cr:YSGG laser for composite restoration removal. ■

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