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Patient and Clinician Experiences When Using a CO_2 Laser for Cavity Preparations: Lessons learned from Prospective Clinical Research

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Abstract: This prospective clinical study evaluated the experiences and preferences of both patients and clinicians when performing class I–V cavity preparation procedures using a 9300 nm CO_2 laser without anesthetic. A total of 233 procedures were performed on 103 patients. Following treatment, patients were asked to describe discomfort/pain levels and preferences for future treatment with either laser treatment or traditional therapy. Additionally, clinicians were asked to rate their experiences with the procedures in three technical domains: speed, ease-of-use, and precision. In total, 98% of patients preferred laser treatment to traditional therapy and 93% of all procedures performed were completed with no anesthesia. Younger patients and patients receiving multiple restorations reported significantly higher discomfort, though discomfort scores were very low overall (below 3 on a 10-point pain scale). While there were significant differences in clinician experiences, each clinician reported having generally high satisfaction using the laser with respect to speed, ease of use, and precision. In conclusion, the 9300 nm CO_2 laser provides clinicians a viable option for cavity preparations in dentistry as evidenced by high rates of anesthesia-free procedures with low reported discomfort, the fact that nearly all patients would opt for laser use on future cavity preparations, and generally positive experiences reported by clinicians.

Keywords: CO_2 laser; cavity preparations; operative dentistry; analgesia

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1. Introduction

Minimally invasive techniques have been developed in many aspects of dentistry including endodontics and the restoration of associated teeth, cavity preparations in operative dentistry, and the use of lasers for surgical procedures [1]. This study will focus on the use of a CO_2 laser to provide minimally invasive cavity preparations with respect to the use of local anesthesia.

Lasers have been used in dentistry in the United States for caries removal and cavity preparation since receiving FDA approval in 1997 [2]. Since this time, the erbium family of lasers, including Er:YAG and Er:YSGG, have demonstrated cutting efficiency without sacrificing vitality of pulpal tissues in many studies from 1988 to 1999 [3–7]. This is due to a combination of factors, including use of water spray, a pulsed mode of energy delivery, and an intermittent laser use. Ablation of enamel from erbium laser energy is caused by the rapid subsurface expansion of the interstitially trapped water within the mineral substrate causing a massive volume expansion and explosion of the surrounding material creating a photoacoustic effect and classic popping sound [2].

Multiple studies prior to 2004 have shown erbium lasers to make cavity preparations in enamel and dentin with minimal-to-no local anesthesia [8–14]. Matsumoto et al. (1996) reported that use of Er:YAG lasers on class V cavities resulted in a pain-free experience for 48/60 (80%) patients and had no adverse reactions [15]. Similarly, Keller et al. (1998) found the Er:YAG laser to be 80% more comfortable than conventional mechanical treatment, required less need for anesthesia, and had high patient preferences with 82% of participants preferring the laser for future caries removal treatments. They concluded that Er:YAG laser therapy was a more comfortable alternative or adjunct to conventional mechanical cavity preparation with air-driven turbine handpieces [16]. Similar results have been reported for children, with 82.5% reporting no pain when using an Er:YAG laser for cavity preparations, and 92% saying they preferred a laser for future studies [17].

While Er:YAG lasers are traditionally more common in dental clinics, there is one 9300 nm CO_2 laser that is FDA-approved for caries removal and cavity preparation (Solea, Convergent Dental, Needham, MA, USA). The characteristics of this wavelength are the ability to ablate hydroxyapatite (HA) and vaporize water, which comprise about 97% of enamel content [18]. When one considers both reflection and absorption, the total energy transferred into HA is much greater at 9300 nm than at the Er:YAG lasers wavelength of 2940 nm (considering the peak absorption of HA occurs at 9600 nm). At this wavelength, the reflection coefficient is low while the absorption coefficient is high [18]. The ability to target HA allows this CO_2 laser to outperform erbium lasers in the cutting of enamel and dentin [18] and has been proposed as another "candidate" (joining Er:YAG) to provide "painless preparations" [19].

CO_2 lasers have also been shown to produce less pain and less risk to pulpal vitality than traditional handpiece therapy. As early as 1994, Walsh showed a 10,600 nm CO_2 laser produced little-to-no pulpal response (178 of 187 procedures) during enamel etching, dentin desensitization, increased fluoride uptake, external resorption, and pulp capping. Furthermore, only four procedures required anesthesia, showing a strong analgesic-like effect of the laser, and there was no post-operative sensitivity or loss of pulpal vitality [20]. Similarly, Wigdor and Walsh (2002) detected no pulpal damage to teeth treated with laser irradiation using a 9600 nm CO_2 laser at energy levels that did not elevate pulp temperature [21]. Finally, in a 2005 in vitro study using a similar 9600 nm CO_2 laser, Moshonov et al. determined the ability to efficiently cut enamel and dentin [22].

While modality and patient experiences are important during any dental treatment, it is also important that clinician preferences are evaluated for any newer treatment technology as this indicates the likelihood that such instruments will be used over the long term. While research on specific use parameters (e.g., ease-of-use, precision, speed) is limited, there is some research on modality preference with Er:YAG lasers. For example, in a survey of 11 clinicians, Evans (2011) reported that they preferred conventional cavity preparation methods over Er:YAG laser use for most (73 of 77) treatments, citing difficulty accessing the caries with the laser handpiece [12].

To the authors' best knowledge, no clinical studies have evaluated the analgesic-like effect of a CO_2 laser during cavity preparation, nor have they evaluated both patient and clinician experiences with this laser in tandem. The null hypotheses of this study were three-fold: 1, patients would report experiencing a high-level of discomfort when a 9300 nm CO_2 laser is used during different dental cavity preparation procedures with and without anesthesia; 2, patients would not prefer CO_2 laser treatments relative to traditional therapy for future treatment; and 3, clinicians would not prefer laser treatment over traditional therapy with respect to speed, ease of use, and precision.

2. Materials and Methods

This prospective clinical study was approved (approval #AZ1059) by the Midwestern University Institutional Review Board. All patients requiring class I–V cavity preparations and presenting at the Dental Institute were invited to participate in the study, provided they met the study inclusion criteria. Between August 2017 and April 2019, 103 patients received 233 resin-bonded composite restorations. Each participant was invited to enroll based on the following inclusion criteria:

1. Having class I, II, III, and/or V carious primary lesions on previously unrestored teeth or having recurrent caries that did not require removal of amalgam.

2. Willingness to begin the preparation without anesthetic.
3. Participants requiring multiple procedures with the laser would be seen to in one appointment. Participants varied in their experience with traditional handpieces with respect to previous dental treatment.

All participants were provided information about the laser treatment, were given possible treatment alternatives, allowed to ask questions, and were given verbal and written informed consent by either the provider or a clinical research coordinator. Prior to starting treatment, all participants were asked to raise their arm upon feeling any discomfort, at which point treatment would be immediately stopped. Participants were also notified that they can stop the procedure and request anesthesia at any point. We also sprayed air and water into their mouths to acquaint the subjects with the feeling of air flow and cold water to help them differentiate these feelings from pain. All prior diagnoses and planned procedures were performed under standard clinical conditions by one of six licensed clinicians. While each clinician was an experienced practitioner with training and certification in use of the CO_2 laser, they had different levels of experience using it. Therefore, supplemental analyses were performed to test for significant differences in reported experiences and patient discomfort among clinicians and over time.

Laser preparations were similar in outline and internal form to conventional handpiece preparations and were performed with a 9300 nm CO_2 laser (Solea Model 2.0, Convergent Dental, Needham, MA, USA) using power values between 4 and 16 W, a 1.25 mm spot size, and 20–60% cutting speed. These correspond to irradiance values ranging from 250 to 1000 W/cm^2 and energy densities values ranging from 0.37 to 1.48 J/cm^2 [23]. Clinicians also used conventional handpieces to finish preparations, based on personal preference.

Immediately following treatment, each participant was provided a short survey asking them to share their experience of discomfort/pain levels, satisfaction with the procedure(s), and their preferred modality for future cavity preparations. In addition, the providing clinician was asked to complete a series of 5-point scales reporting the speed of the procedure, ease of use, and perceived precision. These three scales were summed to construct a 15-point index reflecting the clinician's experience while using the laser (Clinician Experience Index). They were additionally asked whether the patient received anesthesia at any point during the procedure and, if yes, under what conditions. Finally, they were asked to rate patient discomfort on a 10-point scale.

3. Results

3.1. Patient Experiences

The demographics of the final sample population were 53% female with a mean age of 51.44 ± 20 years (mean age females: 53.31 ± 19.9 years; mean age males 48.6 ± 20 years). In total, 57.3% of study participants were receiving treatment on more than one tooth.

There was no significant difference in discomfort by gender (p = 0.672, F = 0.179). Individuals receiving multiple preparations reported significantly higher discomfort than those receiving a single preparation (p = 0.0267, F = 5.065). However, overall discomfort scores were low for both groups (mean discomfort less than 2 of 10, see Figure 1).

Average patient discomfort values were highest for laser treatment without anesthetic (1.6 +/− 1.8) and a combination of laser treatment and traditional therapy without anesthetic (1.2 +/− 1.7).

There was also a low, significant negative correlation between participant age and reported discomfort (p = 0.0032, R^2 = −0.3), with older individuals reporting slightly lower discomfort levels (see Figure 2).

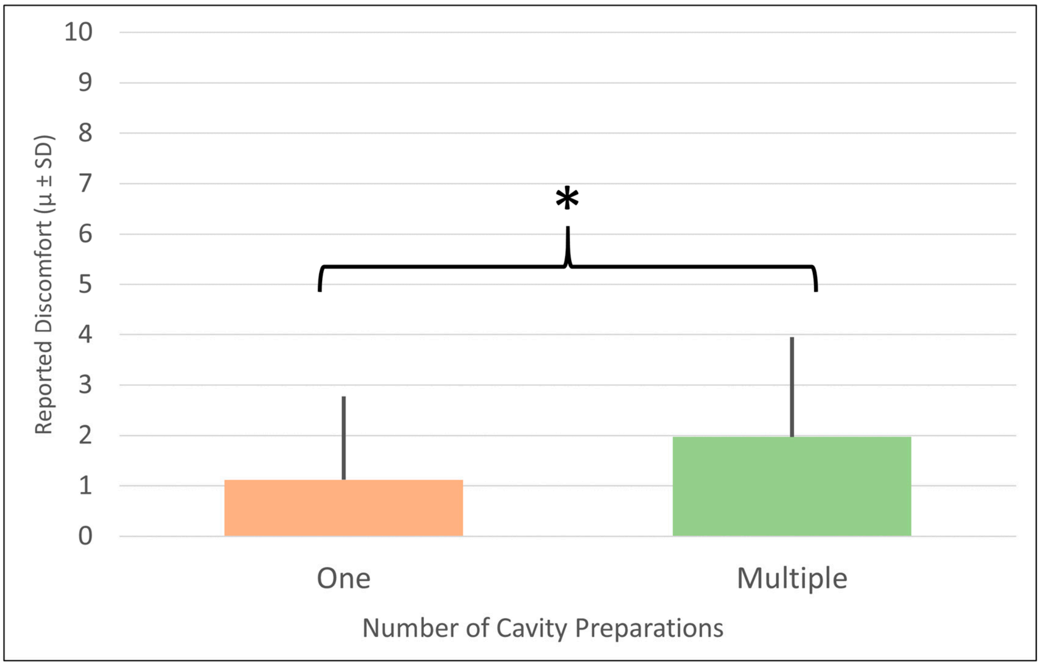

Figure 1. Discomfort reported for participants receiving one versus multiple preparations. 0 = "no discomfort," 10 = "extreme discomfort", * *p*-value < 0.05.

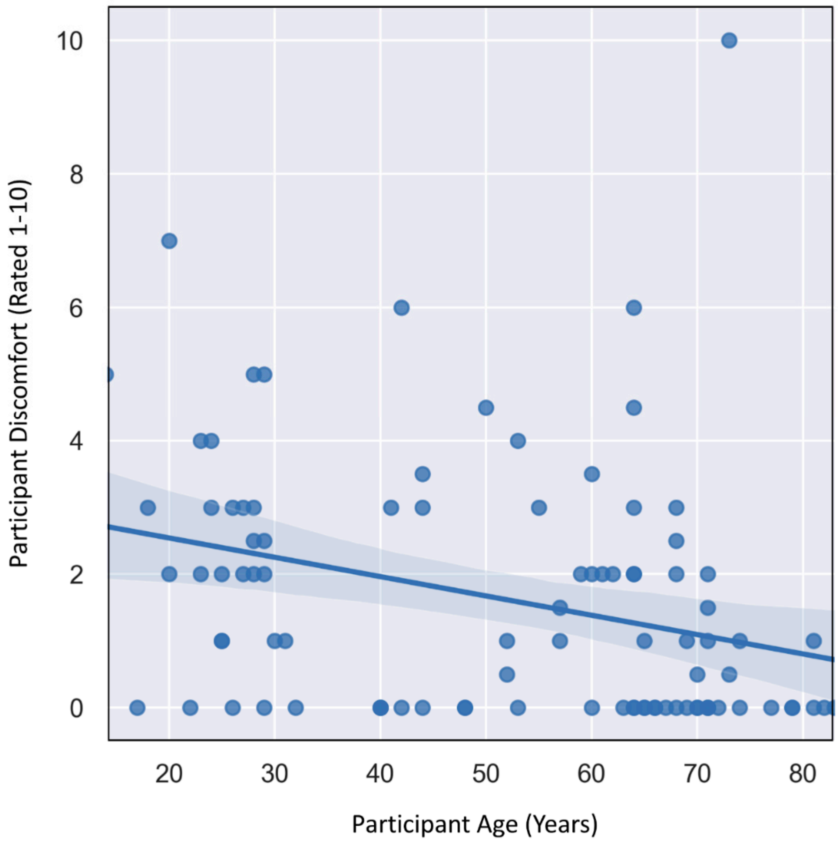

Figure 2. Plot showing patient discomfort regressed on age ($R^2 = -0.3$).

This is corroborated by anesthesia use, where results show that those participants requiring anesthesia during the procedure were significantly younger than those who did not ($p < 0.001$, F = 8.485); however, caution is recommended due to the small sample size for anesthesia recipients (n = 7, see Table 1).

Table 1. Discomfort values by procedure type.

Treatment Given	n	Percentage	Average Discomfort	Range Discomfort
Laser only, with anesthesia	2	2.08	5.0 ± 2.8	3–7
Laser only, no anesthesia	45	46.88	1.6 ± 1.8	0–10
Laser and drill, with anesthesia	5	5.21	3.5 ± 2.6	0–6
Laser and drill, no anesthesia	44	45.83	1.2 ± 1.7	0–6

Table 1: Average discomfort and discomfort range is reported here on a 10-point scale for those subjects reporting discomfort during procedures. Seven subjects did not report this data. Note that values of 0 indicate no discomfort, while values of 10 indicate pain.

For the majority of cases (93%), anesthesia was not requested or required. This was true even when laser use was followed by handpiece use, i.e., nearly half of the anesthesia cases (see Table 1). When asked which treatment option they preferred for future cavity preparations, the majority (98%) would choose the laser over a conventional handpiece treatment: 94% would choose the laser with no anesthetic, and 4% laser with anesthetic. Only 2% of participants would prefer a conventional handpiece treatment with anesthetic for future treatments.

3.2. Clinician Experiences

Results of an analysis of variance show significant differences in the Clinician Experience Index (CEI) while using the laser for cavity preparations (p-value < 0.001, F = 12.17). However, clinicians reported an overall positive rating (12.5 ± 2.37) (see Figure 3) on a scale with an upper limit of 15, and the mean values for each index constituent were over 4 (on a scale with an upper limit of 5). A Pearson Correlation showed no significant relationship between the CEI and participant discomfort (p = 0.16), indicating that the variability in aggregate perceived speed, ease-of-use, and precision did not have a detectable relationship with participant discomfort. Additionally, there was no significant correlation between treatment time (days since first treatment) and patient discomfort (R = −0.055, p = 0.59), indicating that patient discomfort did not appear to change even as more inexperienced clinicians became accustomed to using the laser for cavity preparations.

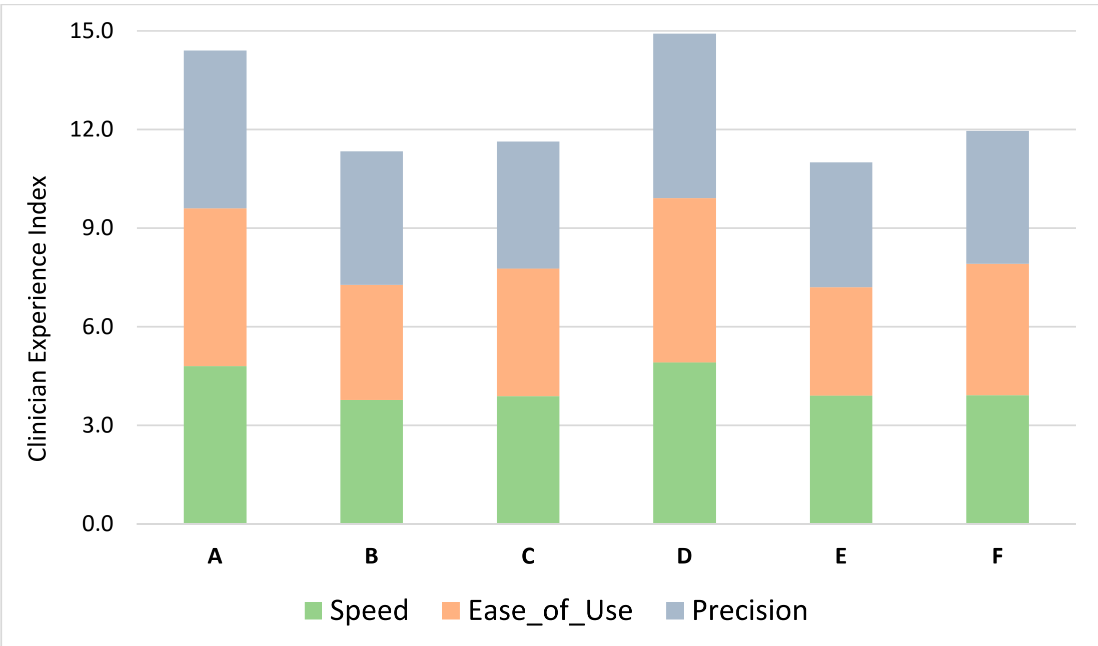

Figure 3. Clinician Experience Index. Individual clinicians (n = 6) are presented on the x-axis while the sum of the 5-point scales for speed, ease of use, and precision is presented on the y-axis.

4. Discussion

Overall, the overwhelmingly positive experiences of patients treated with the CO_2 laser in this study are consistent with prior studies for Er:YAG lasers. Patient preferences for laser over conventional treatments are generally high; however, our patient preference of 98% is higher than values typically reported for Er:YAG laser treatment in children and adults. These reported values have ranged from 72 to 92% [12,16,17,24]. The null hypothesis that patients would not prefer the CO_2 laser to traditional handpieces for cavity preparations was rejected. This is bolstered by the fact that our patient discomfort scores were low, even when supplemental handpiece treatments were performed. This is also similar to reports for Er:YAG lasers, in which pediatric patients experienced less pain with a laser than drill [25], patients are more comfortable with laser treatment than conventional therapy [16], the majority (82.5%) of pediatric patients experienced no pain with laser treatment [24], and laser procedures on children were more comfortable than traditional procedures 67% of the time [24]. The null hypothesis that patients would have a high-level of discomfort during laser cavity preparations was also rejected. Our patients' strong preference not only for lasers, but for no anesthetic, also mirrors results by Walsh (1994) who found that 51 out of 54 patients required no local anesthesia for laser treatments for many different dental procedures [20]. In total, it appears that patient experiences when using a CO_2 laser for cavity preparations is equal to or greater than those reported for Er:YAG laser use.

There were some interesting trends within our sample population, in particular the significant, inverse correlation between discomfort and age, and the higher rates of anesthesia use in younger individuals. The authors suggest that this stems from the relative pulpal proximity to cavity preparations in younger patients and is not related to specific characteristics of the laser.

The CEI demonstrated that all clinicians had generally favorable views of laser cavity preparations. This contrasts with prior work in several ways. In another comparative study, Evans et al. (2000) found that clinicians significantly preferred conventional handpieces for cavity preparations due to the slow cutting speed of the Er:YAG laser and difficulty using the laser handpiece to access cavity preparations [12]. Similarly, Hjertton and Bagesund (2013) found that cavity preparation with an Er:YAG laser took nearly 4 times longer than with a conventional handpiece [26], and Sarmadi et al. (2018) reported that it took 3 times longer [27]. This contrasts with our study, in which the clinicians reported high (positive experience) scores for both speed (4.18 ± 0.86) and ease-of-use (4.13 ± 0.92) on the 5-point scale (see Figure 3). This may be due to the absorption characteristics of the 9300 nm CO_2 wavelength versus the Er:YAG wavelength as previously discussed and the physical characteristics of the Solea handpiece and delivery system. The null hypothesis that clinicians would not prefer the CO_2 laser to traditional handpieces for cavity preparations was also rejected.

This clinical study demonstrated several limitations. To ensure minimal change to standard treatment plans, the clinicians were given no restriction on use of supplemental high and slow speed handpieces in conjunction with laser therapy. This means that some patients received one or both forms of cavity preparation. While not formally investigated, subsequent discussion with the clinicians indicated several reasons for using handpieces during the treatment, including confidence in completing outline and caries removal without tactile sensation, the speed of refining cavity preparations, and concerns over the length of the laser-induced analgesic-like effect. Larger operative procedures including cuspal coverage were also not included in this study.

In addition to the limitations discussed above, it is generally accepted that lasers should not be used to remove amalgam restorations due to the potential aerosolization of mercury. Lasers are also contraindicated in areas of reduced interocclusal space such as distal surfaces of second and third molars. These would be ideal targets for additional studies.

Future studies evaluating the circumstances and reasons that prompt clinicians to use traditional handpieces should be understood and could be addressed with laser education and training. Additionally, studies could be designed investigating the duration of the laser-induced analgesia-like effect in different patient populations (culturally competent dentistry). Furthermore, while we did investigate differences between patients receiving one or multiple preparations in one sitting, we did not explicitly test the effect that different cavity preparation types might have on patient discomfort and clinician experience when using the laser. This is important because some cavity preparations (class V) may be in part or entirely in dentin (more sensitivity) and others (class II) may be technically more challenging (proximal box design).

5. Conclusions

The 9300 nm CO_2 laser provides a new option to Er:YAG and Er:YSGG lasers for performing precision cavity preparations in operative dentistry. Patient experiences demonstrated preference for CO_2 laser cavity preparations versus traditional handpiece cavity preparations. In addition, patients reported a high incidence of pain-free dental treatment without the use of local anesthesia. Clinician experiences show preference for the use of the CO_2 laser compared to traditional handpieces for cavity preparations conducted in this study. They all reported a preference for this laser compared to traditional handpieces with regard to speed of preparation, ease of use, and precision. Based on overall favorable experiences for patients and clinicians, this laser appears to be a preferred option for anesthesia-free cavity preparations.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in this study.

Data Availability Statement: Data sets for this study are located on password-protected computers in the Midwestern University College of Dental Medicine-Arizona research offices.

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Conflicts of Interest: The authors declare no conflict of interest.

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