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Efficiency and Effectiveness of Er:YAG Laser on Carious Tissue Removal

Danielle Cristine Furtado Messias[a], Aline Evangelista de Souza-Gabriel[b], Regina Guenka Palma-Dibb[c], Antonio Luiz Rodrigues Jr[d], Mônica Campos Serra[c]

[a] *Master's Student, Department of Restorative Dentistry, School of Dentistry of Ribeirão Preto, University of São Paulo (USP), Brazil.*
[b] *Research Fellow, Department of Restorative Dentistry, School of Dentistry of Ribeirão Preto, University of São Paulo (USP), Brazil.*
[c] *Associate Professor, Department of Restorative Dentistry, School of Dentistry of Ribeirão Preto, University of São Paulo (USP), Brazil.*
[d] *Assistant Professor, Department of Social Medicine, School of Medicine of Ribeirão Preto, University of São Paulo (USP), Brazil.*

Purpose: The aim of this study was to assess the efficiency (time necessary for carious tissue removal) and effectiveness (caries removal capacity) of the Er:YAG laser using different pulse repetition rates.

Materials and Methods: Fifty-two slabs of carious human dentin were selected, fixed, and a 3-mm² circular area was delimited. According to a randomized complete block design, specimens were assigned to 4 groups (n = 13): Er:YAG laser at three pulse repetition rates (2, 3, and 4 Hz) and carbide bur at low speed (control). Time to remove carious tissue was recorded, and 5 calibrated examiners checked the cavities through tactile and visual analysis.

Results: Concerning the efficiency, Kaplan-Meier analysis demonstrated that the bur was faster than Er:YAG laser, regardless of the frequency. The Kruskal-Wallis test showed a significant difference among groups ($p = 0.0001$). The Wilcoxon test verified that all frequencies were significantly different from the mechanical bur ($p < 0.0001$) and that 2 Hz differed significantly from 4 Hz ($p = 0.0042$). In the analysis of efficacy, medians from five examiners' judgments were used. Interexaminer agreement (Kappa) varied from 0.24 (fair) to 0.75 (substantial). The Student's t-test did not demonstrate a significant difference between 4 Hz and carbide bur ($p = 1.0000$), but both presented greater effectiveness in carious tissue removal than 2 and 3 Hz.

Conclusion: Mechanical drilling was more efficient than Er:YAG laser, regardless of the pulse repetition rate used. Er:YAG laser irradiation with 4 Hz presented similar effectiveness to the carbide bur in a low-speed handpiece.

Keywords: Er:YAG laser, carious dentin, caries removal, pulse repetition rate, efficiency, effectiveness.

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In an effort to develop outstanding methods for carious tissue removal while meeting requirements of conservative, safe and painless dental treatment, laser systems have appeared as a promising alternative technique.[1-4] Among the laser systems currently available, the Erbium:Yttrium-Aluminium Garnet (Er:YAG) laser has been advocated as a viable approach for caries removal providing cavity preparation with minimal thermal effects to the pulp, sound dental tissue, and surrounding soft tissues.[4-6]

The combination of treatment efficacy and low thermal side effects is due to the coincidence of the 2.94-µm wavelength emission with the main absorption band of water (ca 3.0 µm) and also to the great ab-

sorption by OH- groups in hydroxyapatite.[7,8] Er:YAG laser irradiation causes water and cooling components to vaporize,[7] resulting in high steam pressure within the lased tissue. As a consequence, multiple microexplosions occur, which constitute the major principle of Er:YAG laser ablation.[7,8]

Laser irradiation is controlled by different parameter settings which can be varied. Thus, the success of dental treatment can be ascribed to ideal dosimetry.[5,9-12] Studies have shown that some specific parameters can modulate the intensity of dental tissue ablation using Er:YAG laser.[9,13] With regard to the laser settings indicated for dental treatment, the pulse repetition rate (frequency) is one of the most important parameters, being directly related to the laser ablation ability[8,9,13] and the heat generation on dental substrate.[8,9,14]

By varying the irradiation conditions, the Er:YAG laser can induce different modifications of the dental surface. Significant morphological alterations on dental surfaces have been observed when Er:YAG laser was applied using a pulse repetition rate of 4 Hz.[8,15-17] Other clinical reports have demonstrated that Er:YAG laser operating at 2 and 4 Hz promoted effective and safe carious tissue removal, with reduced need for local anesthesia.[3,18]

Investigations have focused on establishing parameters that provide an appropriate ablation of dental hard tissues.[5,8,9,12] However, a consensus has not yet been reached, and the available data did not elucidate the relationship between Er:YAG laser parameters and the ability to remove carious tissue. Therefore, the present in vitro study attempted to evaluate the efficiency (time necessary to remove carious tissue) and effectiveness (caries removal capacity) of Er:YAG laser, using different pulse repetition rates.

MATERIALS AND METHODS

Experimental Design

A randomized complete block design with 13 experimental units per treatment was employed. The factor examined was the method of carious tissue removal at four levels: Er:YAG laser at different pulse repetition rates (2, 3 or 4 Hz) and low-speed carbide bur (serving as control). The response variables were efficiency and effectiveness of the Er:YAG laser, which were evaluated quantitatively and qualitatively, respectively. The former was measured as the length of time to remove carious tissue by the different methods tested. The effectiveness of the Er:YAG laser was independently and blindly evaluated through visual and tactile analyses by 5 examiners using scores 0 (no caries/undefined) and 1 (caries).

Acquisition of Carious Specimens

This study was submitted to and approved by the Ethics Committee of the School of Dentistry of Ribeirão Preto, USP. Carious human teeth, stored in chloramine solution at 4°C, were cleaned with a scaler and water/pumice slurry in dental prophylactic cups. Coronal carious slabs were obtained by sectioning teeth using a double-faced diamond disk (KG Sorensen; São Paulo, SP, Brazil) in a low-speed handpiece (Dabi Atlante; Ribeirão Preto, SP, Brazil). Specimens were eligible if they had an appropriate and a similar thickness of remaining sound tissue and a minimum 3-mm^2 circular carious area. Afterward, samples were fixed with wax on plexiglass plates and individually identified. All specimens were stored at 4°C in distilled water.

Carious Tissue Removal

To facilitate the access to the caries lesion, cavosurface enamel was removed by a diamond bur mounted in a high-speed handpiece. Then, a 3-mm^2 circular area of carious surface was delimited with adhesive tape.

All treatments examined (the sequence of which was randomly determined in each block) were carried out by only one operator. In the control group, a round carbide bur # 4 (KG Sorensen) in a low-speed handpiece with a rotation rate between 3000 and 18,000 rpm was used to remove carious tissue. In experimental groups, carious tissue was removed by an Er:YAG laser device (Kavo Key Laser 2, Kavo; Biberach, Germany) operating at different pulse repetition rates: 2, 3 and 4 Hz (0.4, 0.6, 0.8 W). The laser device was operated with parameters set at 200 mJ, 250-µs pulse duration, and 12-mm irradiation distance (focused mode) under 2 ml/min of water spray. The laser beam spot size was 0.63 mm and a handpiece (2051) with a removable tip was attached to a flexible fiber delivery system.

Efficiency Evaluation

To evaluate the efficiency of the treatments, the length of time needed for caries removal, along with the time spent washing, drying and checking, were recorded by an auxiliary operator.

Table 1 Treatment time medians (s) and proportions of samples in which carious dentin was completely removed in each group

Groups	Efficiency (treatment time)	Effectiveness (score 0)
Er:YAG laser – 2 Hz	113 A	2/13 a
Er:YAG laser – 3 Hz	85 AB	6/13 a
Er:YAG laser - 4 Hz	75 B	12/13 b
Carbide bur at low speed	36 C	12/13 b

Groups that were statistically different from each other ($p < 0.05$) are indicated by different superscript capital letters (in column 2) and lower case (in column 3) ($n = 13$). Score 0 represents samples without evidence of carious tissue.

Effectiveness Evaluation

The effectiveness of carious tissue removal was blindly evaluated by 5 examiners through visual and tactile inspections. Examinations were accomplished under standardized conditions, which included probing the slabs on a scale (50 g), timing the measurements (10 s) and distancing the artificial light source from the slab. In the tactile analysis, the criterion for a caries-free surface was the nonpenetration of the probe into the dentin. In the visual examination, discoloration, consistency, and shine of the dentin surface were the parameters considered for caries diagnosis. Examiners were instructed to assign scores of 0 (no carious tissue) or 1 (carious tissue). In case of doubt between the scores, the lowest score was assigned. For calibration prior to the evaluation process, representative slabs of each score were shown to the five evaluators so they could visualize and probe the cavities.

Statistical Analysis

The efficiency of the methods of carious tissue removal was evaluated using the Kaplan-Meier method of nonparametric survival analysis. The Kruskal-Wallis test was carried out to check for the existence of differences among the experimental groups, and the Wilcoxon test was used for pairwise comparisons. The interexaminer reproducibility was evaluated for visual and tactile analysis, and the results were interpreted according to Landis and Koch.[19] Effectiveness data were analyzed by Fisher's exact test, and the pairwise comparisons were made with the Student's t-test for proportions. All statistical procedures were performed with STATA at a significance level of $\alpha = 0.05$.

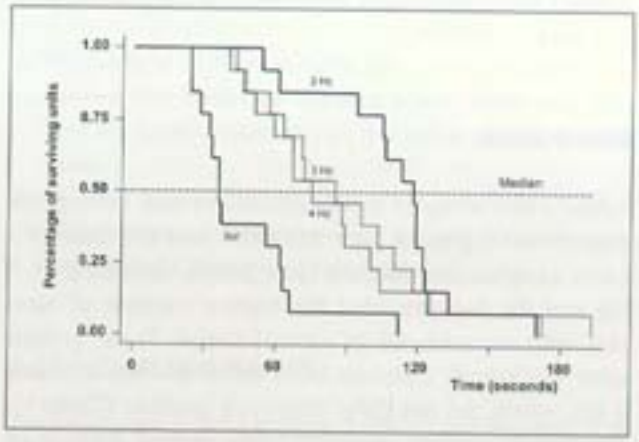

Fig 1 Kaplan-Meier survival curves to show the time taken for carious tissue removal, by experimental groups.

RESULTS

Efficiency

Table 1 summarizes the estimated median from Kaplan-Meier by groups, and Fig 1 illustrates the results. It was observed that carious tissue removal with the carbide bur (control group) was the fastest procedure.

The Kruskal-Wallis test revealed a significant difference among groups ($p = 0.0001$). Pairwise comparisons of groups by the Wilcoxon test showed that when the laser beam operated at 2 Hz, carious tissue removal was significantly slower than when 4 Hz and the bur were used, which differed significantly from one another (Table 1). No significant difference was observed between groups irradiated with 2 and 3 Hz ($p = 0.1157$) nor between 3 and 4 Hz ($p = 0.2246$). The conventional bur treatment was faster than

Table 2 Interexaminer reproducibility among 5 examiners

	A	B	C	D
B	0.243			
C	0.434	0.387		
D	0.446	0.428	0.565	
E	0.495	0.356	0.557	0.747

Er:YAG laser irradiation, regardless of the pulse repetition rate ($p < 0.0001$).

Effectiveness

Fisher's test showed significant differences among the experimental groups ($p < 0.00001$) and the Student's t-test ascertained that the laser beam operating at 4 Hz and the bur provided the highest number of samples with no evidence of carious tissue. These groups were statistically different from those treated at 2 and 3 Hz, which did not differ from one another (Table 1). The interexaminer reproducibility ranged from 0.24 (fair) to 0.75 (substantial), as seen in Table 2.

DISCUSSION

The present study was designed to determine the efficiency and effectiveness of Er:YAG laser for removing carious tissue using different pulse repetition rates. This was based on the fact that carious tissue removal by Er:YAG laser is carried out according to varying parameters and also that pulse repetition rates have a great influence on laser irradiation ability.[8,9,13]

Low pulse repetition rates were used in this study because the carious tissue is less mineralized and contains more water;[20] consequently, the Er:YAG laser provides a greater ablation rate of carious than noncarious dentin. Another factor that influences parameter selection is the carious lesion depth. The thickness of the remaining dentin influences its thermal isolation capability and the transmission of heat to the pulp.[21] In addition, considering that the tissue near the pulp is less mineralized and moister,[22] lower parameters should be applied to remove deep carious lesions. The pulse duration of 250 µs (short pulse) permits an efficient ablation of dental structure[23] and does not result in pulp damage from heat diffusion.[21] The longer the exposure time, the larger the amount of energy transmitted to the surrounding tissue. This energy is lost and is not available for the ablation process. On the other hand, with the use of shorter pulse durations, the ablation threshold will be reached with less energy.[23]

The outcome of this study disclosed that the conventional mechanical method was faster than Er:YAG laser, despite the pulse repetition rate used. Previous investigations[1,3,10,24] also observed that a longer treatment time was required for carious dentin removal by Er:YAG laser, even though these authors do not correlate laser parameters to the efficiency of caries lesion removal. Yamada et al,[4] using Er:YAG laser irradiation at 200 mJ/2 Hz, verified that the time for caries removal with laser was almost twice as long as that using the bur, similar to the present findings when the laser was applied at 2 Hz. On the other hand, Shigetani et al[25] did not find differences in the time for carious dentin removal when comparing Er:YAG laser and a conventional cutting device. However, the pulse repetition rate applied was 10 Hz, which improves the ablation but may compromise the pulpal integrity.[6-8]

The results demonstrated that the treatment time and pulse repetition rate are inversely related. Therefore, Er:YAG laser applied at 4 Hz was more rapid than other tested pulse repetition rates. This could be explained by the fact that an increase in pulse repetition rate inherently leads to a greater number of microexplosions in the same time interval; consequently, laser interaction with the tissue is also greater.[8,9]

Indeed, the pulse repetition rate is described as the most important parameter in the heat deposition on laser-irradiated tissue.[9,14] Even though the heat caused by laser irradiation does not propagate into pulp tissue, the photothermal effect is responsible for structural[15,16,26] and chemical[26] alterations on dental surfaces. Therefore, an increase in laser pulse repetition rate inevitably allows less cooling of dental tissues between one pulse and another.[8,14] These features together are thought to decrease the composite bond strength when Er:YAG laser frequency increases.[27]

Based on these observations, it has been emphasized that the laser ablation speed could be greater when higher parameter settings are utilized, but this might have an influence on the safety and patients' response.[2] Thus, even though a longer preparation time was inevitable, the use of low pulse repetition rates was preferred in order to provide a safe procedure for dental structure and pulp tissue.[2,8]

In this study, although the examiners were previously calibrated, the interexaminer reproducibility varied considerably, which may be explained by the subjectivity inherent to the caries diagnostic process. Even when the evaluators are accurately trained, there is no guarantee that they will agree on diagnoses, since their decisions will be taken based on knowledge and experience previously acquired. Thus, in an attempt to minimize variables and bias of this investigation, factors such as probing pressure, analysis time, illumination, and specimen localization were standardized.

Regarding the effectiveness analysis, most of the laser samples irradiated with 2 and 3 Hz presented residual carious dentin. These results confirm the low ablation capacity with low pulse repetition rates.[9] It is supposed that the laser operator may have accelerated the procedure when it was realized that more time would be necessary to remove all carious dentin. This assumption could explain the presence of carious tissue in samples that required more time to complete the procedure. Er:YAG laser with 4 Hz and carbide bur were both efficacious in caries removal, although the treatment time was greater with laser equipment. Nevertheless, starting from 4 Hz, decomposition of organic constituents and degradation, collapse or even melting of the collagen network occur, decreasing dentin permeability.[16,17]

There have been speculations about the quantity of carious tissue that must be removed in order to preserve the maximum amount of dental structure.[2,8] In this context, it has been shown that some carious dentin may be left behind[2,9] as result of underpreparation.[24] From this point of view, samples in which carious tissue was not completely removed could be considered acceptable, and then the Er:YAG laser at 2 and 3 Hz could be applied for caries management.

It has been discussed that cavity preparation is only a small part of the complete treatment time, which also includes diagnostic procedures, local anesthesia application, and cavity restoration.[3] Thus, since the restoration time is supposed to be the same in laser and bur treatment, and the need for local anesthesia is significantly lower with laser use,[2,18] the entire clinical time with a laser device or mechanical drill should be similar.

It is evident that due to the difficulty in obtaining carious teeth, most of the studies that evaluated Er:YAG laser effects in dental treatment utilized sound teeth.[5,6,8-10,15,16,26,27] Celiberti et al[24] employed the Er:YAG laser for carious tissue removal, but in deciduous teeth. There is a lack of published data on the influence of Er:YAG laser parameters, especially pulse repetition rate, on caries removal. In addition, due to differences in both methodology and scope of the reported research, it is difficult to make reliable comparisons with the findings available in the literature.

Further investigations are required to standardize basic workable parameters to yield optimal and safe ablation of dental hard tissues, as well as to assess the applicability and the real benefits of Er:YAG laser technology in dental practice, before recommendations for its routine application in dental care can be made.

CONCLUSION

Considering the laser device used (KaVo-Key) and the limitations of an in vitro study, our findings show that:

1. Mechanical drill treatment was more efficient (required less time for carious tissue removal) than Er:YAG laser, regardless of the pulse repetition rate used.
2. Er:YAG laser irradiation at 4 Hz presented similar effectiveness (caries removal capacity) to the carbide bur in a low-speed handpiece.

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Contact address: Profa. Dra. Mônica Campos Serra, Faculdade de Odontologia de Ribeirão Preto – USP, Av. do Café, s/no - Monte Alegre - CEP 14040-904, Ribeirão Preto, SP, Brazil. Tel: +55-16-3602-4075; Fax: +55-16-3633-0999. e-mail: mcserra@forp.usp.br