Original papers

Analysis of aerosol generation during Er:YAG laser-assisted caries treatment: A randomized clinical trial

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D – writing the article; E – critical revision of the article; F – final approval of the article

Advances in Clinical and Experimental Medicine, ISSN 1899–5276 (print), ISSN 2451–2680 (online) *Adv Clin Exp Med*. 2024;33(10):1087–1095

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Funding sources
None declared

Conflict of interest
None declared

Received on September 5, 2023
Reviewed on October 8, 2023
Accepted on October 26, 2023

Published online on January 5, 2024

Abstract

Background. Maintaining biosafety in dental practice involves the effective elimination of aerosols produced during dental treatment.

Objectives. To assess the quantity of aerosols and aerobic bacteria in the air during the treatment of caries.

Materials and methods. The study involved 60 patients with a total of 60 molar teeth (n = 60) in the mandible who were divided into 2 groups based on caries treatment method. Group 1 (G1, n = 30) received treatment with a conventional dental turbine (W&H Synea TA-98LC; W&H, Bürmoos, Austria), while group 2 (G2, n = 30) underwent treatment with an Er:YAG (erbium-doped yttrium aluminium garnet) laser (LightWalker, Fotona, Slovenia). Measurements of aerosol particles between 0.3 μm and 10.0 μm near the operator's mouth were taken using the PC200 laser particle counter (Trotec GmbH, Schwerin, Germany). The number of aerobic bacteria in the air was determined using 60 Petri plates with a microbiological medium (Columbia agar with 5% sheep blood) and the sedimentation method. A control group (G3) was established to measure initial aerosol levels and initial total number of bacteria colony-forming units (CFUs) before each treatment.

Results. In G1 (dental turbine), the median value of aerosol particles was 57,021 (42,564–67,568), while in G2 (Er:YAG laser), it was significantly lower at 33,318 (28,463–35,484) ($p < 0.001$). The median total bacteria count per cubic meter of air in G1 (conventional dental turbine + high volume evacuator (HVE)), G2 (Er:YAG laser + HVE) and G3 (control group before caries treatment) were 734 (420–988), 158 (96–288) and 48 (32–74), respectively, with a statistically significant difference between the groups ($p < 0.001$).

Conclusions. The use of Er:YAG laser during caries treatment resulted in a 41.6% reduction in aerosol amounts and a 78.5% decrease in the total bacterial count (TBC) compared to treatment with a dental turbine.

Key words: bacteria, dentistry, aerosols, biohazards

Cite as
Matys J, Gedrange T, Dominiak M, Grzech-Leśniak K. Analysis of aerosol generation during Er:YAG laser-assisted caries treatment: A randomized clinical trial *Adv Clin Exp Med*. 2024;33(10):1087–1095. doi:10.17219/acem/174536

DOI
10.17219/acem/174536

Background

Aerosols, defined as minute suspended particles with prolonged air suspension characteristics, raise concerns in dental procedures due to their capacity to serve as potential vectors for transmitting infectious agents, including bacteria, viruses and fungi.[1–4] Dental aerosols exhibit a spectrum of particle sizes, typically spanning from submicron dimensions (<1 μm) to well over 100 μm in diameter, with the majority falling within the 10–30 μm range.[1,5] The utilization of a dental turbine in conservative dentistry procedures generates elevated concentrations of aerosols, which can be classified into 4 categories: respiratory aerosols, bioaerosols, water spray originating from rotary instruments, and a composite of bioaerosols and water spray characterized by significant dispersion potential.[6,7] It is important to emphasize that aerosol particles of smaller dimensions, particularly those with a diameter less than 5 μm, pose an increased risk as they have the potential to be inhaled into the finer recesses of the pulmonary system.[8] Conversely, particles exceeding 50 μm in diameter typically lead to the formation of splatter patterns and are not inhalable, rendering them less hazardous.[6,9] Therefore, the reduction of water spray quantities in various dental procedures holds paramount importance in mitigating the risk of viruses and bacteria transmission within the field of dentistry.[1,2,10]

The utilization of water–air spray cooling in dental rotary tools results in the emission of aerosols that contain various microorganisms, such as viruses, bacteria and fungi.[8,11,12] The imperative lies in the reduction of aerosol production during dental procedures, as it directly impacts the biological safety of the dental environment.[13] Our prior investigations, conducted both in vitro and in vivo, have demonstrated the generation of substantial quantities of potentially perilous aerosols during dental treatments, thereby elevating the risk of pathogen transmission.[1,2,14] The use of rotary dental devices, including both high-speed and low-speed ones, in addition to ultrasonic scalers, is associated with the most elevated levels of aerosol concentration and the potential for transmitting bacteria, viruses and fungi within the dental clinical setting.[5,8,15] Transmission pathways for pathogens during dental procedures involve aerosols containing saliva and blood, along with dental instruments and handpieces that may become contaminated.[11,16,17] Aerosols possess significant potential for carrying and disseminating viral and bacterial infections. Consequently, it is imperative for dental practitioners to acknowledge and mitigate the risk of microbial transmission, particularly when dealing with patients in the incubation phase of illness, those who are unaware of their condition, or those choosing to conceal their disease.[18–20]

Scientific literature has demonstrated the positive impact of lasers on various dental treatments as they eradicate viruses, bacteria and fungi.[21–23] Certain lasers create aerosols or induce cavitation effects in fluids.[24–28] Erbium lasers find extensive application in the dental field, including in procedures like caries removal, endodontic irrigation, periodontal and implant treatments, as well as orthodontic bracket and prosthetic crown removal.[28–36] There is a growing recognition of the potential health hazards linked to aerosols generated by laser procedures. These aerosols are often comprised of smaller particles in contrast to respiratory droplets, which differ significantly in size from viruses even though viruses are typically much smaller than the cells they target.[2,24] Existing literature confirms the use of lasers for virus inactivation in dentistry.[25,26] However, it is crucial to note that heat generated by lasers and vaporization of soft tissue may lead to smoke production, which may contain infectious particles.[24,25]

The composition of aerosols resulting from cavity preparation with high-speed turbines and erbium lasers is influenced by a complex interplay of factors related to the tools, tissues, settings, patient factors, operator techniques, environmental conditions, and the size and airborne characteristics of the particles generated.[1,2,37] Minimizing the overall volume of water spray and aerosols within dental facilities plays a crucial role in reducing the potential for airborne transmission of pathogens.[18,38] Dental procedures frequently employ suction devices, such as salivary ejectors and high-pressure evacuators, to eliminate aerosols. An in vitro study demonstrated that an enhanced suction device with an extended suction tip significantly reduced aerosol levels during in vitro caries removal. This study further established that broader suction systems outperformed conventional suction tips in aerosol removal. Furthermore, when compared to other instruments used for caries removal, an Er:YAG (erbium-doped yttrium aluminium garnet) laser coupled with a traditional evacuator generated fewer aerosols.[1,2] The current study aimed to determine whether these in vitro findings translate to in vivo benefits for patients treated in dental offices.

Objectives

The principal aim of this study was to determine whether there is a discernible difference in the volume of aerosols and bacterial count generated during caries treatment in a dental office when utilizing either a conventional dental turbine or an Er:YAG laser in a human model.

Materials and methods

Study design and setting

The study was a randomized controlled clinical trial. Prior to commencing, permission was granted by the Local Ethics Committee at the Faculty of Dentistry's (Wroclaw Medical University; approval No. KB-737/2021), and all participants provided informed consent in adherence to the Declaration of Helsinki. The clinical trial was registered with ClinicalTrials.gov (identifier: NCT05988359).

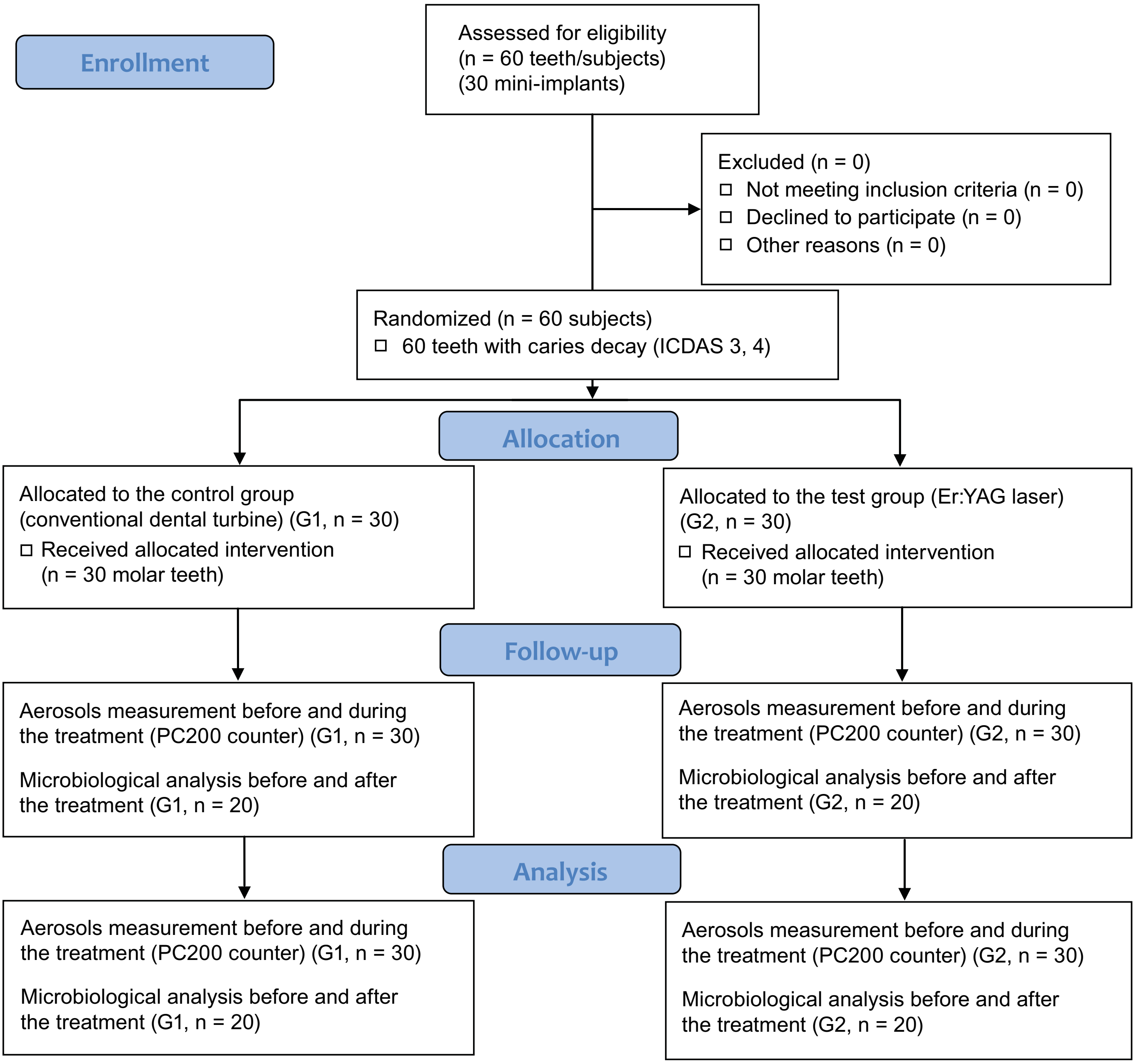

Fig. 1. Participants who were treated in accordance with the Consolidated Standards for Reporting Trials (CONSORT) 2010 guidelines

Participants

The study included a cohort of 60 participants comprised of 39 women and 21 men, all presenting with moderate caries decay as per the International Caries Detection and Assessment System (ICDAS 3 and 4) in a total of 60 molar teeth located in the mandibular region. The mean age of the participants was 29.4 ±5.8 years. The sample size for each group, consisting of 30 study participants, was determined using G*Power software (Kiel University, Kiel, Germany). This calculation was based on our prior research,[1,2] considering a significance level of 0.05, effect size (d) of 0.71, a 95% confidence interval (95% CI), and 85% statistical power. All participants were selected to meet specific inclusion criteria, which included having moderate caries decay (ICDAS 3 and 4), non-use of anti-inflammatory medications, non-smoking status, absence of systemic illnesses, no antibiotic usage within the last 2 months, no uncontrolled diabetes or untreated periodontal disease, and having received hygienist treatment beforehand (Fig. 1).

Data sources and measurement

Participant groups and procedure for treating caries

The study involved treating 60 patients with caries decay for a total of 60 molar teeth located in the mandible. The study participants were separated randomly

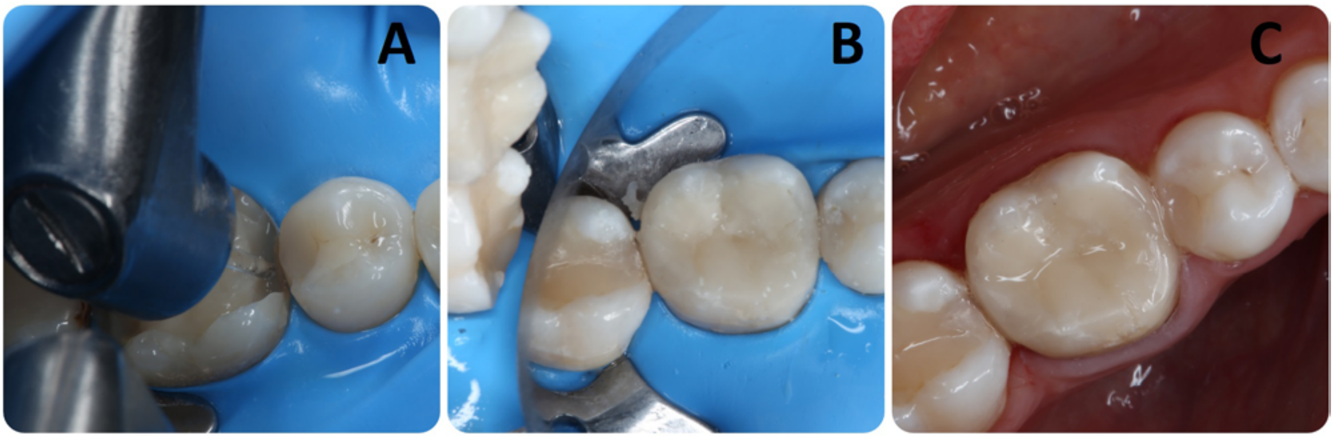

Fig. 2. Clinical pictures of caries treatment with Er:YAG laser. A. Er:YAG laser contra-angle handpiece (LightWalker, Fotona, Slovenia); B. Immediately after cavity restoration with composite material; C. Final tooth cavity restoration

into 2 groups utilizing the www.randomizer.org website. The 1st group, denoted as G1 (n = 30), underwent caries treatment utilizing a round diamond bur (#014) on a W&H Synea TA-98LC high-speed handpiece (W&H, Bürmoos, Austria). The handpiece operated at a speed of 200,000 revolutions per minute (rpm) with water cooling maintained at a flow rate of 30 mL/min. The mean time for caries preparation was 60 s.

The 2nd group, referred to as G2 (test, n = 30), underwent caries treatment using the Er:YAG laser contra-angle handpiece (LightWalker, Fotona, Slovenia) (Fig. 2). Laser parameters consisted of an energy setting of 300 mJ, frequency set at 20 Hz, power set at 6 W, energy density 38.2 J/cm^2, power density 764 W/cm^2, medium short pulse (MSP) mode (100 µs), and a tip diameter of 1 mm. Additionally, a water/air coolant at a flow rate of 30 mL/min was used. The mean time for caries preparation was 200 s. In both experimental groups, a standard evacuator EM19 EVO (Monoart® Euronda, Vicenza, Italy) was deployed for the removal of aerosols generated during caries treatment. Prior to each treatment session, baseline aerosol levels and the initial total bacterial count (TBC) expressed in colony-forming units (CFUs) were assessed, establishing the G3 control group.

Protocol for measuring aerosols

The assessment of aerosol particle quantities (primary outcome) at the examination sites was conducted using the PC200 counter (Trotec GmbH, Schwerin, Germany). The counter's nozzle was positioned 2 cm away from the operator's mouth. Utilizing the aerosols detector, measurements were taken for 6 distinct aerosol fractions, spanning diameters from 0.3 µm to 10.0 µm. The counter was initiated immediately prior to each treatment session and deactivated upon completion of caries treatment. The cumulative count of particles encompassing all fractions was tabulated, and subsequent mean values were compared between the groups.

Quantifying the concentration of airborne particulate matter using sedimentation analysis

The Koch sedimentation technique was employed to ascertain the total count of aerobic bacteria (secondary outcome) present within the air of a dental facility. Sixty Petri plates containing Columbia agar with 5% sheep blood medium were used for the quantification of aerobic bacteria. Twenty plates were exposed for a duration of 60 min before the commencement of treatment (designated as the control, G3, n = 20). Subsequently, they were closed promptly prior to the initiation of caries treatment. Forty additional plates were opened at the outset of the treatment, employing either a conventional turbine (G2, n = 20) or the Er:YAG laser (G1, n = 20), and were sealed after a 60-min interval. Each caries treatment procedure lasted less than 30 min. Measurements were conducted at a height of 1 m above the floor and situated 2 m from the patient's mouth, positioned centrally within the office. The bacterial specimens were incubated for a 48-h period at a temperature of 37°C, and the extent of microbiological contamination was computed as the overall number of CFUs per m^3 of air using the formula:

$$L = a \times 1000/\pi r^2 \times k,$$

where:
L – microbial contamination level in [CFU/m^3];
a – the quantity of bacterial colonies cultivated on the plate;
r – radius of the Petri dish [cm];
k – the exposure time coefficient, denoted as 'k,' is determined by multiplying the exposure time 't' (measured in min) by 1/5.

Dental office surface and air standardization

Between each patient, surfaces were cleaned by wiping down all areas, including dental chairs, lasers and handles, with a disinfectant cleaner to remove visible debris. The aspiration system was then cleaned with a cleaning solution

Table 1. The quantity of aerosol particles measured at the mouth of the operator before (control/initial measurement) and after caries treatment using either an Er:YAG laser or a dental turbine (ANOVA Kruskal–Wallis test)

Groups	ANOVA Kruskal–Wallis; H (2; n = 90) = 78,3711; p < 0.001			
	n	median	lower-top quartiles	p-value
Turbine + HVE (G1)	30	57,021	(42,564–67,568)	G1 vs G2; <0.001 G1 vs G3; <0.001 G2 vs G3; <0.001
Er:YAG + HVE (G2)	30	33,318	(28,463–35,484)	
Control (G3)	30	29,129	(29,178–29,784)	

ANOVA – analysis of variance; HVE – high volume evacuator; n – number of measurements; G1 – group 1; G2 – group 2; G3 – group 3 (control).

run through it to clear debris and disinfect internal components. Suction lines were also disinfected to maintain proper function. External surfaces were treated with disinfectant, which was left for 10 min. The dental office environment underwent a series of standardization procedures. The office space encompassed an area of 20 m^2 with all windows and doors securely closed and the air conditioning system deactivated. An air purifier, specifically the NV1050 model manufactured by Novaerus (Dublin, Ireland), boasting an air exchange rate of 800 m^3/h, was employed to maintain aerosol levels within the range of 28,000–30,000 particles/m^3 for each procedure. Continuous monitoring was conducted at 1-min intervals while the air purifier was in operation. Each dental treatment was conducted after completion of air standardization within the designated range. Control measurements were taken by positioning a sensor at the central point of the office, and it took on average approx. 5 min to cleanse the air to the specified levels.

Statistical analyses

Normal distribution of the data was tested using the Shapiro–Wilk test (Supplementary Fig. 1–6). Normal distribution was not observed for most of the data. The quantity of aerosols, as measured using the particle's detector, and TBC (expressed as CFU/m^3) throughout the caries treatments were analyzed using Kruskal–Wallis analysis of variance (ANOVA) and a post hoc Dunn's test with Bonferroni correction. For statistical analysis, Statistica software v. 13.3 (StatSoft Inc., Tulsa, USA) was used. Significance was attributed to any values falling below the threshold of $p = 0.05$.

Results

Quantity of aerosol particles generated during caries treatment (primary outcome)

The Er:YAG laser produced a significantly lower level of aerosol particles at the operator's level during caries treatment in contrast to the standard dental turbine ($p < 0.001$). The 1st group (conventional dental turbine + HVE) had a median aerosol value of 57,021 (42,564–67,568), while G2 (Er:YAG laser + HVE) had a lower value of 33,318 (28,463–35,484). When comparing the results of both groups, it was found that use of the Er:YAG laser reduced aerosol amounts during caries removal by 41.6% compared to the high-speed turbine. However, it is important to note that for both methods, the initial level of aerosols in the office 29,129 (29,178–29,784) significantly increased at the end of the treatment ($p < 0.001$) (Table 1).

Concentration of aerobic bacteria after caries treatment (secondary outcome)

The median count of total bacteria per m^3 of air in G1 (conventional dental turbine + HVE), G2 (Er:YAG laser + HVE) and G3 (control group before caries treatment) were 734 (420–988), 158 (96–288) and 48 (32–74), respectively. During caries treatment, employing a dental turbine (G1, $p < 0.001$) and Er:YAG laser (G2, $p < 0.001$) led to a notable increase in bacteria CFU levels in the dental office air compared to the initial levels in the control group (G3). Use of the Er:YAG laser resulted in a significantly lower total bacteria count compared to the standard dental turbine ($p < 0.001$). Additionally, utilizing the Er:YAG laser during caries removal resulted in a 78.5% decrease in TBC compared to the standard dental turbine (Table 2).

Discussion

Ensuring air purity in dental facilities is vital in mitigating the risk of microbial transmission.[6,39] Various measures, including air decontamination, protective masks and surface disinfection, have been adopted to enhance safety and promote good air quality within treatment rooms.[6,20] The primary approach to mitigating bioaerosol transmission during dental procedures centers on eradicating the accumulation of bioaerosols and cooling sprays within the oral cavity.[1,2] The purpose of this study was to examine aerosol levels in the air during caries treatment by removing generated aerosols before they enter the dental office environment. This strategy resulted in a substantial decrease in microbial risks present in the dental office air, with a 41.6% decrease in aerosol levels achieved using the Er:YAG laser

Table 2. The median value of the total bacterial count (measured in CFU/m^3) assessed at the central location within the dental office (ANOVA Kruskal–Wallis test)

Groups	ANOVA Kruskal–Wallis; H (2, n = 60) = 52,5042; p < 0.001			
	n	median	lower-top quartiles	p-value
Turbine + HVE (G1)	20	734	(420–988)	G1 vs G2; <0.001 G1 vs G3; <0.001 G2 vs G3; <0.001
Er:YAG + HVE (G2)	20	158	(96–288)	
Control (G3)	20	48	(32–74)	

ANOVA – analysis of variance; HVE – high volume evacuator; TBC – total bacteria count; CFU – colony-forming unit; n – number of microbiological plates; G1 – group 1; G2 – group 2; G3 – group 3 (control).

compared to the high-speed dental handpiece. Moreover, using the Er:YAG laser, there was a 78.5% decline in total bacteria count when treating caries compared to standard dental turbines. These in vivo findings corroborated previously published in vitro studies.[1,2]

The principal aim of this study was to assess the null hypothesis that there is no notable disparity in aerosol generation between dental caries decay removal using a burr on a turbine and an Er:YAG laser. For both methods, an additional dental standard high-volume evacuator (HVE) was applied. The study findings revealed that the use of Er:YAG laser for dental caries treatment considerably reduced the level of aerosol in the dental office compared to standard dental turbine, which is consistent with our previous in vitro study.[2] Moreover, in the present trial, use of the Er:YAG laser reduced aerosol particles in dental office air by 41.6% compared to the high-speed turbine. These results align with our previous published in vivo research, in which we observed a 40% decrease in the quantity of aerosols when treating dental decay utilizing a broader evacuator in conjunction with a dental turbine.[14] Other researchers have also recently demonstrated the effectiveness of using HVE to reduce the concentration of aerosols in dental facilities.[10,24,40,41] Results from Harrel et al.[40] and Jacks[10] showed significantly better efficiency of HVE than salivary ejector for aerosol removal, which is consistent with our previous in vitro studies. Findings from in vivo research by Nulty et al.[41] were congruent with our results, providing further evidence of aerosol reduction during dental procedures. Our present study is the first randomized clinical trial conducted in vivo that examined the use of an Er:YAG laser and not only different suction systems or rotary instruments.

It should also be highlighted that the findings of comparative studies conducted with various mouth rinses, including chlorhexidine, reinforce the efficacy of this method.[42] These studies have consistently demonstrated a significant reduction in the number of microorganisms that may escape from a patient's mouth through aerosols during dental treatments.[42] However, in the air exhaled by the patient and within the tissues affected by caries, there are still bacteria which, in order to maintain the safety of medical staff, should be eliminated during the dentist's work in the patient's oral cavity. The hydration level during the removal of carious tissues (dentin) plays a significant role in shaping the characteristics of the aerosol produced during dental procedures. Research by Timbrell and Eccles[43] highlighted that grinding enamel and dentine in surgical procedures without water cooling results in a fine aerosol with a substantial respirable fraction, posing potential health risks to dentists. Additionally, the use of water spray in high-speed grinding demands attention due to its high respirability, raising concerns about droplets potentially acting as efficient carriers of microorganisms into the dentist's lungs. To mitigate these risks, it is essential to utilize effective high-volume suction apparatus. The function of erbium lasers on tissue is dependent on the interaction with water, which results in the elevation of hydrogen molecule vibrations and thermal energy.[27,44] This creates movement within the liquid, resulting in water evaporation and the potential production of aerosols during dental procedures such as caries removal, endodontics and periodontal pocket treatment.[30,31,34,45–47] However, our previous in vitro and present in vivo investigations found that the Er:YAG laser application resulted in a significantly lower increase in aerosols compared to other procedures in a dental office.[1,2] In contrast to initial measurements, the dental turbine and Er:YAG laser increased aerosols by 96% and 11.4%, respectively. In our previous research, we implemented 3 distinct Er:YAG lasers.[2] These lasers operate based on comparable physical phenomena for operation on tissues, but discrepancies in cooling fluid delivery methods may lead to dissimilar aerosol particle generation during dental procedures.[1,2,24] We discovered that the type of cooling system utilized in the laser has a notable effect on the generation of aerosols.[2] The erbium lasers used in the present study use coolant supply lines with 3 endpoints in the handpiece's head. When using this kind of laser, the tissue is cooled with 3 water streams.[2] The outcomes from our prior in vitro experimentation showed that the aerosol increase in the air was greater for the laser with its cooling system built in the handpiece than for the laser where the water and air supply lines were integrated into the tip (and not just into the handpiece). However, we did not utilize the laser with a cooling system in the tip during our research due to its inefficacy in vaporizing tooth enamel, primarily because of its lower maximal power.[1,2]

The global spread of bacterial infections has raised serious public health concerns.[48–50] The 2nd aim of the study was to evaluate the level of aerobic bacteria in the air when treating dental caries decay. Our findings indicate an increase in bacterial count in CFU/m^3 in the air for both treatment methods (dental turbine and laser) compared to initial measurements before treatment. Other studies have also reported an increase in airborne bacterial, fungal load during dental treatment and significant room contamination when high-speed instruments were used.[18,51] In a study by Manarte-Monteiro et al.,[51] it was revealed that the level of airborne bacteria increased at both 0.5 m and 2 m distances during endodontic treatment. Correspondingly, Rautemaa et al.[18] found substantial room contamination within the 0–2 m range when high-speed dental instruments were employed, resulting in an average of 970 CFU/m^3/h. Additionally, Szymańska[4] demonstrated that fungi concentration in the air ranged from 4 × 101 CFU/m^3 to 34 × 101 CFU/m^3 during caries dental decay removal. Our current study found that the highest median bacterial count was observed for conventional turbines with 734 (420–988) CFU/m^3 after 1 h. In contrast, the Er:YAG laser led to a 78.5% reduction in TBC compared to the conventional handpiece used at the patient's mouth during caries treatment. These findings coincide with our recently published research, in which we found an 84.5% reduction of TBC during caries treatment with a high-speed turbine when compared to standard HVE for the wider intraoral suction system.[14]

Limitations

The study contains several limitations. The primary reason why there are restrictions on the use of erbium lasers instead of conventional rotary instruments in dentistry is their high cost. Furthermore, operating these devices safely in vivo requires expertise and knowledge. In this study, the conventional Koch sedimentation method, which has limited accuracy, was used to measure the TBC in the office air. Other measurement methods for microbial air analysis, such as air sampling with impactors (e.g., Andersen samplers), need to be evaluated in a dental office. Another limitation is the scarcity of existing literature addressing the impact of different water systems in dental handpieces on aerosol levels. Furthermore, our clinical research compared the amount of aerosol particles and TBC generated by dental turbine vs Er:YAG laser without identification of specific colonies. Considering the influence of oral microflora on aerosol composition is important for ensuring accurate and comparable results in any study or research involving dental procedures. However, for studies that identify bacterial colonies, it is recommended to have patients with similar oral microflora.

Further research is necessary to assess the efficacy of Er:YAG lasers for decontamination during dental treatment, as well as randomized clinical trials to evaluate their impact on reducing aerosols. Additionally, investigations should be conducted to determine how other methods for caries treatment, such as dental sandblasting, affect aerosol levels and microbial air concentration.

Conclusions

The use of a traditional high-speed handpiece for treating dental caries produces a significant number of aerosols that can linger in the air of a dental clinic for a prolonged time, which can increase the risk of transmission of infection between medical staff and patients. This study demonstrated a significant reduction in the amount of aerosols generated when using an Er:YAG laser compared to a standard dental turbine. Additionally, the Er:YAG laser significantly reduced bacterial amounts in the office air compared to the dental turbine. The incorporation of erbium laser technology during dental caries therapy not only contributed to the enhancement of air quality within the treatment area, but also played a pivotal role in elevating the broader biological safety standards within the dental office setting.

Supplementary data

The Supplementary materials are available at https://zenodo.org/doi/10.5281/zenodo.10043159. The package contains the following files:

Supplementary Fig. 1. Results of the Shapiro–Wilk test for TBC in group 1 (G1).

Supplementary Fig. 2. Results of the Shapiro–Wilk test for TBC in group 2 (G2).

Supplementary Fig. 3. Results of the Shapiro–Wilk test for TBC in group 3 (G3).

Supplementary Fig. 4. Results of the Shapiro–Wilk test for aerosol amount in group 1 (G1).

Supplementary Fig. 5. Results of the Shapiro–Wilk test for aerosol amount in group 2 (G2).

Supplementary Fig. 6. Results of the Shapiro–Wilk test for aerosol amount in group 3 (G3).

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

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