issn 2193-4665 • Vol. 12 • Issue 1/2020

1/20

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international magazine of laser dentistry

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Dr Stefan Grümer

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Dear laser friends and colleagues,

We all believe in a bright future for laser dentistry, a specialist field that is guided by experience and driven by innovation. It can be argued that advancements in laser dentistry should be made not only in terms of hardware, but also in terms of software.

Against this background, I would like to cordially invite you to join us for the upcoming annual meeting of the German Association for Laser Dentistry (Deutsche Gesellschaft für Laserzahnheilkunde—DGL), which will be held on 6 and 7 November 2020 in Bremen in Germany. Packed with scientific lectures from highly esteemed colleagues and technological innovations from the industry, the conference is considered a definite highlight by many who regularly seek out renowned dental training events. This 2020 annual meeting will be held as joint event together with the 3rd Future Congress of the German Association of Dental Implantology (Deutsche Gesellschaft für Zahnärztliche Implantologie—DGZI). In this way there will be ample opportunity for extensive interdisciplinary exchange with colleagues through shared lectures, poster presentations and industry exhibits.

With so-called "table clinics" the programme will feature yet another novelty on the first congress day on Friday: during round table presentations led by experienced trainers, small groups of participants will have the opportunity to discuss various topics revolving around laser dentistry and oral implantology with a view to synergetic effects between these two specialist fields. The participants will also be allowed to switch between tables, allowing them to get a glimpse into many of the topics discussed. The conference will put particular focus on practice-oriented aspects, which laser enthusiasts can implement effortlessly and rapidly into their daily clinical work.

With this in mind, I welcome you to Bremen this autumn and I wish you a great and interesting read with this first 2020 issue of *laser—international magazine of laser dentistry*!

Dr Stefan Grümer


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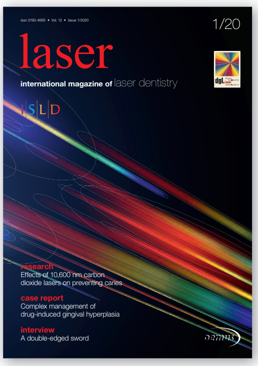

Effects of 10,600 nm carbon dioxide lasers on preventing caries

A literature review

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Introduction

Although dentistry has benefitted from technological advancements in recent years, dental caries remains a major oral health problem in most industrialised and non-industrialised countries affecting more than half of schoolchildren and a large majority of adults.[1] Dental caries is a localised chemical dissolution of dental hard tissues caused by the action of acidic by-products of the metabolic processes of cariogenic biofilm.[2] Conventional non-invasive strategies for caries prevention include oral health education, reduction of sugar consumption, use of fluoride, and application of pit and fissure sealants. Fluoride principally works by hindering the process of demineralisation of enamel and dentine and promoting remineralisation of tooth surfaces with early signs of mineral loss. Pit and fissure sealants generate a physical barrier to prevent the access of dental plaque and its acid products from damaging the enamel surface. However, dental sealants are only effective on the pit and fissures and not the smooth surfaces of teeth. New strategies, such as casein phosphopeptide amorphous calcium phosphate[3] and micro- or nanohydroxyapatite compounds, have been proposed to control the balance between demineralisation and remineralisation. It is essential to develop new caries preventive methods to control the disease. A novel, non-invasive approach is the use of laser irradiation on enamel or dentine in preventing caries development. A number of studies reported the potential of laser irradiation on tooth roots or enamel in inhibiting formation of caries lesions.[4–9]

Several types of laser were studied for caries prevention. The wavelengths of neodymium-doped yttrium aluminium garnet (Nd:YAG) lasers (λ = 1,064 nm) and argon lasers (λ = 488–514 nm) make them difficult to be absorbed by enamel. On the other hand, carbon dioxide (CO_2) lasers (λ = 9,000–11,000 nm) are highly absorbed by dental hard tissues and thus have good potential for use in caries prevention.[7,9] The first CO_2 laser adopted a mixture of nitrogen, helium, and CO_2, and CO_2 acted as the active laser medium.[10] Subsequent CO_2 lasers produced various emission laser lines with wavelengths ranging from 9,000 to 11,000 nm. The most common laser lines of CO_2 lasers are centred at 9,300; 9,600; 10,300; and 10,600 nm, respectively. CO_2 laser wavelengths have a higher absorption coefficient to hydroxyapatite than water. A conventional CO_2 laser-emitting light at 10,600 nm is well-absorbed by minerals, while 9,600 nm has the best absorption coefficient to hydroxyapatite followed by 9,300 nm.[1] However, the 10,600 nm CO_2 laser has been commonly used in medicine and dentistry, and most of the commercially available CO_2 lasers operate only at this wavelength. The effect of CO_2 lasers in caries prevention has been studied since the 1960s,[1] when CO_2 lasers (10,600 nm) were discovered to significantly inhibit enamel caries progression.[7] Significantly less demineralisation was also found in CO_2 laser-treated (λ = 10,600 nm) dentine than non-lased dentine.[9] Furthermore, promising effects of combined CO_2 laser irradiation and fluoride treatment in preventing enamel and dentine caries were reported.[11–13] However, the mechanism of caries prevention of CO_2 lasers remains to be elucidated. A literature search using the databases PubMed, Scopus and Web of Science revealed no comprehensive review to evaluate studies investigating the effects of actions of CO_2 lasers in caries prevention. Therefore, the objective of this paper was to systematically review the evidence regarding the effects of CO_2 lasers (λ = 10,600 nm) on preventing dental caries.

Methods

Search strategy

Two investigators (KL and ISZ) performed a systematic search of articles archived in three databases, PubMed, Scopus and Web of Science. The following keywords were used to identify relevant articles: [(CO_2 laser) OR (carbon dioxide laser)] AND [(dental caries) OR (tooth remineralisation)]. There was no publication year limit, and the last search was made on 31 January 2019. Studies published in English through 2018 and archived in the

PubMed, Scopus, and Web of Science databases were chosen. A list of potentially eligible articles was compiled of publications featuring the keywords (Fig. 1).

Study selection and data extraction

Records identified from database searches were checked for duplication. The titles and abstracts from the potentially eligible list were screened after removing duplicate publications. Articles that did not focus on the effects of CO_2 lasers on preventing dental caries were excluded after screening of titles and abstracts. The remaining articles were retrieved with full texts. The reference lists of all the included articles were screened to identify all possibly eligible studies. The inclusion criterion for selecting studies for this review was that studies investigated the effects of CO_2 lasers on preventing enamel and dentine caries, including their combined effect with topical fluorides on caries progression. For the included papers, the following information was recorded: publication details (authors and years), methods, outcome assessments (various criteria for studying the prevention of caries: reduction of carbonate content, lesion depth, microhardness, mineral loss, surface morphology, and bacterial counts), and the main findings. Any disagreements on study inclusion or data extraction were discussed by the two authors with a third author (OYY) until consensus was reached.

Results

The initial literature search identified 543 potentially relevant articles (143 articles in PubMed, 221 in Scopus, and 179 in Web of Science). A total of 285 duplicate records were removed. After screening the titles and abstracts, 236 articles that were classified as literature reviews, case reports, non-English articles, or irrelevant studies were excluded. No additional relevant publications were found from the references of the selected papers. Finally, 22 articles were found to meet the inclusion criteria and were included in this review. Among these articles, nine studies examined the action of CO_2 lasers on preventing enamel caries (Tab. 1), three studies investigated the effect of CO_2 lasers on preventing dentine caries (Tab. 2), eight studies investigated the effect of CO_2 lasers combined with topical fluorides on enamel (Tab. 3), and three studies examined the effect of CO_2 lasers combined with topical fluorides on dentine (Tab. 4).

Effects of CO_2 lasers on preventing caries of enamel and dentine

Nine studies investigated effects of 10,600 nm CO_2 lasers on morphological and chemical changes of enamel as well as on the reduction of enamel demineralisation. Concerning the microhardness analyses, CO_2 laser-treated enamel surfaces showed significantly higher values than those of negative control.[14,15] Polarised light microscopy evaluation revealed that laser-treated enamel groups showed significantly lower lesion depth compared with the non-lased controls,[16,17] and the decreased lesions represented up to 87 % inhibition of the caries progression.[8] The values of mineral loss of enamel calculated from cross-sectional microhardness analyses were statistically lower in laser-irradiated groups than

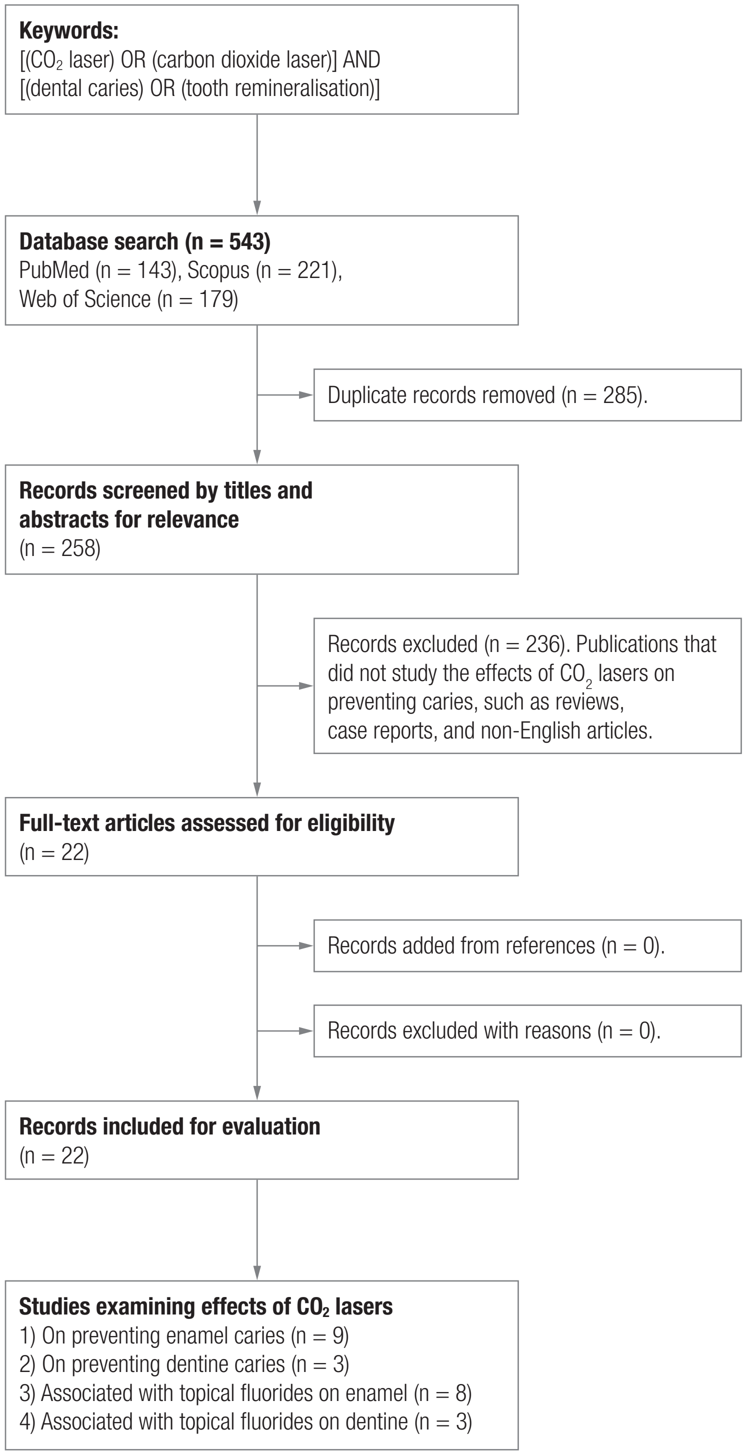

Fig. 1: Flowchart of the literature search.

Authors, year	Methods	Main findings
Vieira et al. 2015[14]	Human enamel was irradiated with CO_2 laser before FTRS and EDX. They were subjected to pH cycling before MHT and SEM.	Irradiated enamel increased microhardness and reduced carbonate content more than negative control. Melting and recrystallisation of enamel occurred after irradiation.
Correa-Afonso et al. 2012[15]	Human enamel irradiated with CO_2 laser was subjected to pH cycling before MHT, PLM, and SEM.	Enamel increased microhardness and reduced demineralisation after irradiation. No fusion, melting, or exposure of enamel prisms was found on the irradiated enamel.
Souza-Gabriel et al. 2010[18]	Human and bovine enamel were irradiated with CO_2 laser before SEM. They were subjected to pH cycling before MHT.	Enamel showed melting and recrystallisation after irradiation. It was more resistant to demineralisation than the negative control.
Esteves-Oliveira et al. 2009[17]	Bovine enamel was irradiated with CO_2 laser before SEM. It was subjected to pH cycling before PLM.	Irradiated enamel showed no ablation, melting, or cracks. It was more resistant to demineralisation than the negative control.
Steiner-Oliveira et al. 2006[20]	Human enamel was irradiated with CO_2 laser before FTRS and SEM. It was subjected to pH cycling before MHT.	Irradiated enamel had less carbonate content and mineral loss than the negative control. Enamel showed melting and fusion after irradiation.
Klein et al. 2005[19]	Human enamel was irradiated with CO_2 laser before SEM. It was subjected to pH cycling before MHT.	Enamel surfaces showed melting and fusion after laser irradiation. They had less demineralisation than the negative control.
Hsu et al. 2000[16]	Human sound enamel with organic matrix removal or not was treated with CO_2 laser and subjected to pH cycling before PLM, microradiography, and SEM.	Irradiated enamel had no surface melting or crater after irradiation. It had less mineral loss and lesion depth than other groups. An interaction effect was found between laser irradiation and enamel organic matrix content.
Featherstone et al. 1998[7]	Human enamel was irradiated with CO_2 laser and then subjected to pH cycling before MHT.	Irradiated enamel showed less mineral loss than the negative control.
Kantorowitz et al. 1998[8]	Human enamel irradiated with CO_2 laser was examined by SEM and subjected to pH cycling before MHT.	Irradiated enamel surfaces showed little or no morphological changes. They had less mineral loss than the negative control.

EDX = energy-dispersive X-ray, FTRS = Fourier-transform Raman spectroscopy, MHT = microhardness testing, PLM = polarised light microscopy, SEM = scanning electron microscopy

Table 1: Summary of studies of effects of CO_2 (10,600 nm) lasers on enamel.

those in non-lased groups.[7,8,16,18–20] There was an interaction effect between the CO_2 laser irradiation and the organic matrix content of enamel on lesion depth and mineral loss of enamel ($p < 0.05$).[16] The enamel with the removal of organic content (non-organic enamel) had a 38 % reduction in lesion depth and a 74 % reduction in mineral loss after laser irradiation when compared to the non-organic enamel without laser irradiation. Both reductions were significantly lower than the results for the lased normal enamel but greater than those for the non-lased enamel.[16] CO_2 laser irradiation could induce chemical changes in enamel. Fourier-transform Raman spectroscopy showed a reduced carbonate content for laser-treated enamel when compared with non-treated ones,[14,20] while there were no statistical differences for calcium and phosphorus components between irradiated groups and the control by energy-dispersive X-ray fluorescence spectrometry measurements.[14]

Observations under scanning electron microscopy revealed evidence of melting and fusion in the enamel samples treated with CO_2 lasers,[14,19,20] and melting and fusion were more frequent in the treated groups that underwent more than one laser application.[14] Enamel surfaces exhibiting melted structures were several times bigger than the prismatic structures and fusion across the prism boundaries.[14] It was verified that a laser-modified layer with a coalescence of crystals was presented in human enamel surfaces, forming an irregular solid mass.[18] A homogeneous and smooth recrystallisation was also observed on the fused enamel surfaces.[14,18] However, some studies found that the treated enamel areas showed little or even no morphological changes.[8,16] The irradiated enamel surfaces exhibited a similar appearance to the non-lased controls,[17] and no signs of surface melting, ablation, crater formation, cracks, or fissures could be observed using the parameters showing caries inhibition effects.[16,17] Three studies investigated the effects of a 10,600 nm CO_2 laser on morphological features of dentine as well as on the reduction of dentine demineralisation.[9,21,22] Root dentine surfaces irradiated with a CO_2 laser with fluences from

Authors, year	Methods	Main findings
de Melo et al. 2014[21]	Human root surfaces irradiated with CO_2 laser were subjected to pH cycling before MHT.	Irradiated root surfaces were more resistant to demineralisation than the negative control.
de Souza-Zaroni et al. 2010[22]	Human root surfaces were irradiated with CO_2 laser before SEM. They were subjected to pH cycling before MHT.	Irradiated root surfaces showed melting and resolidification. They showed less mineral loss than negative control.
Nammour et al. 1992[9]	Human root surfaces irradiated with CO_2 laser were subjected to cariogenic challenge before SEM, microdensitometry measurements, and microradiography.	Root surfaces appeared smooth after irradiation. Root surfaces showed melting with no dentinal openings, and they showed more resistant demineralisation than the negative control.
MHT = microhardness testing, SEM = scanning electron microscopy		

Table 2: Summary of studies of effects of CO_2 (10,600 nm) lasers on dentine.

4.0 to 6.0 Jcm^{-2} showed evidence of melting and resolidification under scanning electron microscopy, and a cracking appearance was more evident on those samples treated with 5.0 and 6.0 Jcm^{-2}.[22] Longitudinally fractured samples had a layer of dentine with no tubular structure (20–70 µm thick), whereas the dentinal tubules retained the normal structure below the sealed layer.[9] The values of mineral loss were significantly lower in the laser-irradiated dentine groups than the non-irradiated controls.[21,22] Additionally, laser-induced inhibitory effects on dentine demineralisation were observed when fluences reached or exceeded 4.0 Jcm^{-2}.

Effects of CO_2 lasers combined with topical fluorides on enamel and dentine

Eight studies investigated the combined effects of 10,600 nm CO_2 laser irradiation and the application of topical fluoride on enamel. The results of these studies varied. Four studies found that there was a synergistic