CO2 Laser: Evidence Based Applications in Dentistry

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1. Introduction

Ever since Kumar Patel introduced lasers in 1960s', researchers have been looking into its possible applications in the field of dentistry. Researchers have investigated the effects of laser radiation on teeth, bone, pulp and oral mucosal tissues (Taylor, Shklar, & Roeber, 1965). CO2 lasers have been used extensively in medical field and the first laser to be approved by FDA for dental application was Nd:YAG (Neodymium-Yttrium-Aluminum-Garnet) in 1990s. Since then many types of lasers including CO2, Er:YAG (Erbium-Yttrium-Aluminum-Garnet), Diode, Er Cr:YSGG (Erbium-Chromium-Yttrium-Scallium-Gallium-Garnet) have been approved for dental use. FDA approved Er:YAG for dental hard tissue in 1997 and has approved other types of lasers for soft and hard tissue procedures in many area of dentistry.

Many authors have reported the use of Carbon Dioxide (CO_2) lasers for soft tissue applications in dentistry (Pick & Pecaro, 1987a; White et al., 1998). The Food and Drug Administration (FDA) granted clearance for marketing CO_2 lasers for soft tissue procedures such as frenectomy, gingivectomy, biopsies, and removal of benign and malignant lesions because CO2 laser energy is well absorbed by water. Specific indications for use in dentistry include apthous ulcer treatment, coagulation of extraction sites, sulcular debridement and intraoral soft tissue surgeries such as ablating, incising, and excising (U.S. FDA 510(k) marketing clearance) as shown in Table 1.

In this chapter, we will discuss basic design, tissue interactions, evidence based clinical applications, and future of dental applications of CO2 lasers.

2. Basic equipment design & tissue interactions of CO2 laser

The growth of CO2 laser applications in Dentistry has grown substantially with its wavelength bands ranging from 9.4 and 10.6 micrometers. The laser medium consists of water or air cooled gas discharge (Carbon dioxide, nitrogen, hydrogen, xenon, helium) that helps in producing a beam of infrared light by activating the footswitch. The original CO_2 lasers were continuous wave or interrupted pulse durations of about 0.5 sec to 50 msec with non contact delivery and large beam diameters up to 1mm and larger. Because, the delivery mode is non-contact this results in lack of tactile sensation to the operator. Previous studies with these continuous wave CO_2 lasers showed a variety of structural and ultrasonic changes of the hard tooth structure. These included cracking, flaking, crater formation, charring, melting, and recrystallizaton due to the highly efficient absorption of CO_2 wavelengths by the apatite mineral of hard tissues (Boehm, Rich, Webster, & Janke, 1977; J. D. B. Featherstone & D. G. A. Nelson, 1987; McCormack, 1995; Stern & Sognnaes, 1964; Stern, Vahl, & Sognnaes, 1972). All dental tissues have different absorption coefficient for various wavelength depending on water, blood, pigment, and mineral content. For example, Nd:YAG and Diode lasers are absorbed by dark pigments making them ideal for soft tissue procedures. Tissue component that maximally absorbs CO2 wavelength is water followed by apatite (Gouw-Soares et al., 2004). Because of this CO2 lasers have been proven to be the gold standard for intra-oral soft tissue applications for decades. Thermal effects and various parameters settings of CO2 lasers have also been studied extensively (Leighty, Pogrel, Goodis, & White, 1991; Malmström, McCormack, Fried, & Featherstone, 2001). These studies indicated that application of CO_2 laser created unacceptable thermal damage to adjacent tissue. Because of these reasons early CO_2 laser system had been limited by their continuous wave operations and delivery system constraints. Lasers parameters such as power, repetition rate, average power and highest peak power play a role in surgical and collateral effects. Studies have concluded that high repetition rate, high peak power and lower average power yield favourable clinical results (Wilder-Smith, Dang, & Kurosaki, 1997).

Device Trade Name	Wavelength (micro mm)	Most Absorption	Recommended Use	FDA Approval
Opus 20 Dental laser system	10.6	Water	Soft Tissue	Yes
N/A	9.6	Appetite	Hard tissue	No
N/A	9.3	Appetite	Hard Tissue	No
Smart CO2	10.6	Water	Soft Tissue	Yes
CO2DENTA	10.6	Water	Soft Tissue	Yes

Table 1. Examples of CO2 lasers available in market for dental use

Due to the lack of tactile sensation, their use in hard-tissue applications is not favorable. With new technologies, dental laser manufacturers now claim to have shorter pulse durations (as short as 150 microsecond pulse duration) with beam diameters of as small as 100 microns. This allows for cooling of tissues between pulses and results in minimal thermal damage. These lasers are now marketed for soft tissue intraoral procedures as described earlier. The laser is usually equipped with various hand pieces and tips of differing diameter for tissue ablation as shown in Figure 1. The hand piece is usually the size of a dental drill and the spot size that is emitted from these hand pieces allows for greater accuracy resulting in minimal damage to the surrounding tissues. As these lasers operate the best in pulse or super pulse infrared mode, they are able to remove precise amount of tissues with each pulse emission.

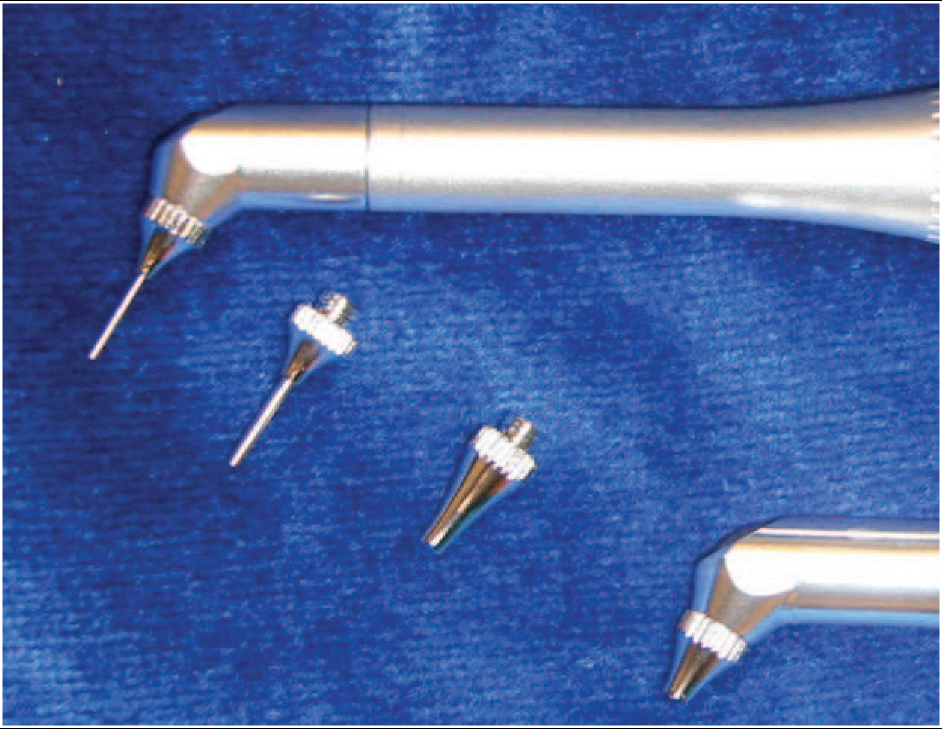


Fig. 1. CO2 laser hand piece with different tips marketed by GPT Dental

3. Evidence based clinical applications

Numerous studies have been done pre and post FDA approval to improve the technique and provide best practice guidelines for the clinicians. A report published by American Dental Association (ADA) in 2001 describing the challenges in the future of oral health care mentioned the role of laser applications. The report specifically mentioned that more clinical research and technical developments in CO2 laser delivery systems will promise to expand its clinical applications beyond soft tissue procedures (Seldin, 2001). Although CO2 laser 10.6micron wavelength is absorbed by water and even though 9.3micron is absorbed in hydroxyapetite, it is primarily a soft tissue laser (Convissar & Goldstein, 2003). Even before CO2 laser received FDA approval for soft tissue procedures in 1990's, many studies have looked at its hard tissue applications in 1980's. Table 2. Lists CO2 laser application in various dental procedures (Sulewski JG).

3.1 Soft tissue procedures

One of the earlier case series by Pick and colleagues reported soft tissue procedures using Sharplan 743 CO2 and Xanar Ambulase lasers. In a Clinical trial 250 patients were treated for conditions ranging from, gingival hyperplasia, benign and malignant lesions (along with conventional surgery), incisional & excisional biopsy, red-white lesions, and haemorrhagic and coagulation disorders. They concluded that CO2 laser provided bloodless field, less post-operative discomfort, tissue coagulation, and better accessibility in some areas of oral cavity compared to scalpel surgery (Pick & Pecaro, 1987b). The advantages compared to scalpel wounds also included site-specific wound sterilization; minimal swelling and scarring but slower healing; reduced necessity for suturing; decreased incidence of mechanical trauma; shorter operative time; favorable patient acceptance; decreased use of local anesthesia; and little or no postoperative pain (Pick & Powell, 1993; White et al., 2002; Wigdor et al., 1995). Literature also reported increased levels of hyaluronic acid in laser wounds compared to scalpel wounds, a chemical that plays a key role in wound repair (Pogrel, Pham, Guntenhoner, & Stern, 1993). With increased use of CO2 lasers clinically, adjacent tissue interaction and damage has been an issue. Studies have reported on chemical and thermal interaction of CO2 lasers with surrounding tissue. In vitro study using 9.3 micrometers Duolase CO2 laser (Medical Optics Inc.) investigated variations in incision depth and width, collateral damage, and bone charring using continuous mode (1-9W average power; 1-10W peak power; 0.5-500Hz; 1, 20, 200miliseconds), superpulse (1-7W average power; 20W peak power; 170-1170hz; 300microseconds) and optipulse (0.72-1.20W average power; 60-100W peak power; 10-40Hz; 300microseconds) mode with various parameter combinations. They concluded that superpulse and optipulse mode with lower average powers and higher peak powers created narrow and deep cuts. Also, almost no charring was noticed with optipulse mode. Optipulse mode reduced the collateral damage by the factor of 10 compared to continuous mode (Wilder-Smith et al., 1997).

Area of Dentistry	Procedure
Oral & maxillofacial surgery	Abscess incision and drainage, Hemostatic assistance, Fibroma removal, Oral papillectomy, Exposure of nonerupted or partially erupted teeth, Implant recovery, Lesion (tumor) removal, Vestibuloplasty, Frenectomy, Frenotomy, Operculectomy, coagulation
Oral Medicine	Aphthous ulcer treatment, Biopsies (incisional/excisional), Leukoplakia
Pre-prosthetic procedures	Crown lengthening (soft tissue only), Tissue retraction for impression
Periodontal procedures	Sulcular debridement, Gingival excision/incision, laser assisted new attachment procedure, Gingivectomy/gingivoplasty
Endodontics	Pulpotomy, Pulpotomy, as an adjunct to root canal therapy and retreatment cases, Removal of filling material such as gutta-percha or resin
Restorative uses	resin curing, teeth whitening agent activation, caries detection, pit and fissure sealants, enamel treatment to increase caries resistance, enamel etching for resin bonding procedures, caries removal, tissue ablation

Table 2. CO2 Laser soft tissue applications

3.2 Endodontics (apicoectomy, root canal debridement)

Hard tissue applications of continuous wave CO2 lasers have been limited due to thermal damage, charring effect and resultant rough tooth surface. Due to its high absorption overlap with phosphate in enamel apetite crystal, all radiation is absorbed in thin enamel (<10 um). This makes heat transfer as the main way of energy transport leading to thermal damage to pulp (Wigdor et al., 1995). Conversely studies have shown that high reflectivity (9%-50%) at 9.3- and 9.6um wavelengths may pose a safety concern and it requires accurate knowledge of radiation dose while doing treatment (Fried, Glena, Featherstone, & Seka, 1997). In 1990's TEA (Transversely excited atmospheric pressure) 10.6um pulsed (0.1-2usec) CO2 laser had the best reported success in ablating dental hard tissue. However, high plasma induction with TEA CO2 laser posed problems with decreased ablation efficiency and damage due to shock wave rendering it unacceptable for clinical use (Wigdor et al., 1995). Since the 9.6micrometer CO2 laser wavelength is highly absorbed in appetite crystals, it presents a future potential for its applications in cavity preparation, apicectomies and other hard tissue procedures. In vitro study using Scanning Electron Microscopic (SEM) images reported cleaner dentinal surface with fusion and recrystallized dentine following apicectomy and root treatment with pulsed TEA 9.6micrometer CO2 laser (Gouw-Soares et al., 2004). Contrasting results were reported in a more recent SEM analysis study. The study compared the marginal permeability and dentinal surface texture following apicectomy performed with burs and CO2 laser. Authors attributed rougher surface and less favourable marginal fit following CO2 laser treatment to the use of continuous wave mode, no cooling agent and less experience of the operator with CO2 laser (Lustosa-Pereira et al., 2011).

3.3 Periodontal procedures

Advantages of using CO2 laser for periodontal procedures have been accepted by American Academy of Periodontology in its position paper. Its ability to provide dry surgical field and haemostasis has been proven useful in periodontal surgical procedures. Additionally CO2 laser use has shown mixed results when used for periodontal pocket debridement in addition to mechanical debridement, pocket reduction, attachment gain, decreased microorganisms, and guided tissue regeneration cases (Convissar & Goldstein, 2003; Matthews, 2010; Wigdor et al., 1995). Porcine mandible study evaluating efficacy of newer micropulse 10.6um CO2 laser showed clinically acceptable results in coagulation, incision depth and width, time required to perform procedure, with minimal hard tissue damage on accidental exposure but surface melting with direct exposure to laser (Vaderhobli, White, Le, Ho, & Jordan, 2010). Other studies have also reported thermal side effects like dentin cracking, carbonization, and melting following CO2 laser use on root surfaces (Matthews, 2010).

3.4 Other restorative uses

Preventive uses of CO2 laser have been well researched. Literature suggests that 9.3 and 9.6um wavelength (pulse width <100usec) at a specified pulse rate has higher efficiency than 10.6um in heating dentin/enamel surface leading to desired crystallization and fusion of surface layer for sealing effect (McCormack, Fried, Featherstone, Glena, & Seka, 1995; Wigdor et al., 1995). A case report by Dederich, suggested to use 15W for 0.2sec duration to achieve dentinal sealing effect with CO2 laser without detrimental effect to pulpal tissue (Dederich, 1999). Furthermore, researchers showed that pulsed CO2 laser produced >1000 celsius temperature increase at the surface, enough to melt and recrystalize enamel and minimal changes deeper than 40um which is critical to avoid collateral damage (J. D. Featherstone & D. G. Nelson, 1987; Wigdor et al., 1995). For dental decay, CO2 lasers have mixed results ranging from thermal damage, dentin/pulp sterilization, and mineralization under treated surface (Melcer, 1986). Surface etching with CO2 laser showed 300% increased in dentin resin bond but no change in enamel bonding (Obata et al., 1999; Wigdor et al., 1995). Superpulse CO2 laser produced fastest debonding of orthodontic brackets (Obata et al., 1999). CO2 laser has also been used in otherwise hopeless prognosis cases of vertical root fracture with radiographical success at one-year follow-up. Teeth bleaching agent activation with CO2 laser causes higher temperature changes and due to lack of controlled clinical trials, ADA does not support its clinical use (Luk, Tam, & Hubert, 2004; N/A, 1998).

4. Future of dental applications of CO2 lasers

The future looks promising for CO2 laser use in the field of dentistry. We need more clinical research specifically randomized clinical trials to evaluate effectiveness of CO2 laser compared to traditional methods. The evidence will help develop standard clinical guidelines for practicing dentists.

5. Conclusion

Currently, CO2 lasers have been used widely in dentistry for soft tissue procedures. More research will help provide practice guidelines. Clinical research including randomized trials are needed to provide specifications for parameter settings, delivery mode, and other guidelines for hard tissue procedures. More information regarding shorter wavelength CO2 lasers in recent years makes future of CO2 laser promising in dentistry.

6. Acknowledgment

We would like to thank Lutheram Medical Center- Department of Dental Medicine for providing support for this project.

7. References

Boehm, R., Rich, J., Webster, J., & Janke, S. (1977). Thermal stress effects and surface cracking associated with laser use on human teeth. J Biomech Eng, 99, 189-194.

Convissar, R. A., & Goldstein, E. E. (2003). An overview of lasers in dentistry. [Case Reports, Review]. Gen Dent, 51(5), 436-440.

Dederich, D. N. (1999). CO2 laser fusion of a vertical root fracture. J Am Dent Assoc, 130(8), 1195-1199.

Featherstone, J. D., & Nelson, D. G. (1987). Laser effects on dental hard tissues. [Research Support, U.S. Gov't, P.H.S.]. Adv Dent Res, 1(1), 21-26.

Featherstone, J. D. B., & Nelson, D. G. A. (1987). Laser effects on dental hard tissues. Advances in Dental Research, 1(1), 21-26.

Fried, D., Glena, R. E., Featherstone, J. D., & Seka, W. (1997). Permanent and transient changes in the reflectance of CO2 laser-irradiated dental hard tissues at lambda = 9.3, 9.6, 10.3, and 10.6 microns and at fluences of 1-20 J/cm2. [In Vitro

Research Support, U.S. Gov't, P.H.S.]. Lasers Surg Med, 20(1), 22-31.

Gouw-Soares, S., Stabholz, A., Lage-Marques, J. L., Zezell, D. M., Groth, E. B., & Eduardo, C. P. (2004). Comparative study of dentine permeability after apicectomy and surface treatment with 9.6 microm TEA CO2 and Er:YAG laser irradiation. [Research Support, Non-U.S. Gov't]. J Clin Laser Med Surg, 22(2), 129-139. doi: 10.1089/104454704774076190

Leighty, S. M., Pogrel, M. A., Goodis, H. E., & White, J. M. (1991). Thermal effects of the carbon dioxide laser on teeth. Lasers in the life sciences, 4(2), 93-102.

Luk, K., Tam, L., & Hubert, M. (2004). Effect of light energy on peroxide tooth bleaching. J Am Dent Assoc, 135(2), 194-201; quiz 228-199.

Lustosa-Pereira, A. C., Pozza, D. H., Cunha, A., Dedavid, B. A., Duarte-de Moraes, J. F., & Gerhardt-de Oliveira, M. (2011). Analysis of the morphology and composition of tooth apices apicectomized using three different ablation techniques. Med Oral Patol Oral Cir Bucal, 16(2), e225-230.

Malmström, H. S., McCormack, S. M., Fried, D., & Featherstone, J. D. B. (2001). Effect of CO2 laser on pulpal temperature and surface morphology: an in vitro study. Journal of Dentistry, 29(8), 521-529.

Matthews, D. C. (2010). Seeing the Light--the truth about soft tissue lasers and nonsurgical periodontal therapy. J Can Dent Assoc, 76, a30.

McCormack, S. M. (1995). Scanning electron microscope observations of CO2 laser effects on dental enamel. Journal of Dental Research, 74(10), 1702-1708.

McCormack, S. M., Fried, D., Featherstone, J. D., Glena, R. E., & Seka, W. (1995). Scanning electron microscope observations of CO2 laser effects on dental enamel. J Dent Res, 74(10), 1702-1708.

Melcer, J. (1986). Latest treatment in dentistry by means of the CO2 laser beam. Lasers Surg Med, 6(4), 396-398.

N/A. (1998). Laser-assisted bleaching: an update. ADA Council on Scientific Affairs. J Am Dent Assoc, 129(10), 1484-1487.

Obata, A., Tsumura, T., Niwa, K., Ashizawa, Y., Deguchi, T., & Ito, M. (1999). Super pulse CO2 laser for bracket bonding and debonding. Eur J Orthod, 21(2), 193-198.

Pick, R. M., & Pecaro, B. C. (1987a). Use of the CO2 laser in soft tissue dental surgery. Lasers in Surgery and Medicine, 7(2).

Pick, R. M., & Pecaro, B. C. (1987b). Use of the CO2 laser in soft tissue dental surgery. Lasers Surg Med, 7(2), 207-213.

Pick, R. M., & Powell, G. L. (1993). Laser in dentistry. Soft-tissue procedures. Dent Clin North Am, 37(2), 281-296.

Pogrel, M. A., Pham, H. D., Guntenhoner, M., & Stern, R. (1993). Profile of hyaluronidase activity distinguishes carbon dioxide laser from scalpel wound healing. Ann Surg, 217(2), 196-200.

Seldin, L. W. (2001). Future of Dentistry: Today's Vision: Tomorrow's Reality: American Dental Association, Health Policy Resources Center.

Stern, R. H., & Sognnaes, R. F. (1964). Laser beam effect on dental hard tissues. J Dent Res, 43(5).

Stern, R. H., Vahl, J., & Sognnaes, R. F. (1972). Lased enamel: ultrastructural observations of pulsed carbon dioxide laser effects. Journal of Dental Research, 51(2), 455-460.

Sulewski JG, (2010). Making the most of 16th Annual conference and exhibition: A practical orientation for attendees. Academy of Laser Dentistry, Miami, Florida.

Taylor, R., Shklar, G., & Roeber, F. (1965). THE EFFECTS OF LASER RADIATION ON TEETH, DENTAL PULP, AND ORAL MUCOSA OF EXPERIMENTAL ANIMALS. Oral Surg Oral Med Oral Pathol, 19, 786-795.

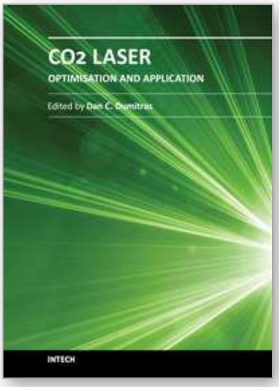
Vaderhobli, R. M., White, J. M., Le, C., Ho, S., & Jordan, R. (2010). In vitro study of the soft tissue effects of microsecond-pulsed CO(2) laser parameters during soft tissue incision and sulcular debridement. [In Vitro, Research Support, Non-U.S. Gov't]. Lasers Surg Med, 42(3), 257-263. doi: 10.1002/lsm.20888

White, J. M., Chaudhry, S. I., Kudler, J. J., Sekandari, N., Schoelch, M. L., & Silverman Jr, S. (1998). Nd: YAG and CO2 laser therapy of oral mucosal lesions. Journal of clinical laser medicine & surgery, 16(6), 299.

White, J. M., Gekelman, D., Shin, K. B., Park, J. S., Swenson, T. O., Rouse, B. P., . . . Oto, M. G. (2002). Laser interaction with dental soft tissues: What do we know from our years of applied scientific research?

Wigdor, H. A., Walsh, J. T., Jr., Featherstone, J. D., Visuri, S. R., Fried, D., & Waldvogel, J. L. (1995). Lasers in dentistry. [Case Reports, Research Support, Non-U.S. Gov't, Research Support, U.S. Gov't, Non-P.H.S., Research Support, U.S. Gov't, P.H.S., Review]. Lasers Surg Med, 16(2), 103-133.

Wilder-Smith, P., Dang, J., & Kurosaki, T. (1997). Investigating the range of surgical effects on soft tissue produced by a carbon dioxide laser. J Am Dent Assoc, 128(5), 583-588.



CO2 Laser - Optimisation and Application
Edited by Dr. Dan C. Dumitras

ISBN 978-953-51-0351-6
Hard cover, 436 pages
Publisher InTech
Published online 21, March, 2012
Published in print edition March, 2012

The present book includes several contributions aiming a deeper understanding of the basic processes in the operation of CO2 lasers (lasing on non-traditional bands, frequency stabilization, photoacoustic spectroscopy) and achievement of new systems (CO2 lasers generating ultrashort pulses or high average power, lasers based on diffusion cooled V-fold geometry, transmission of IR radiation through hollow core microstructured fibers). The second part of the book is dedicated to applications in material processing (heat treatment, welding, synthesis of new materials, micro fluidics) and in medicine (clinical applications, dentistry, non-ablative therapy, acceleration of protons for cancer treatment).