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Mini review

Potential applications of Erbium:YAG laser in periodontics

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Objectives: Since lasers were introduced for the treatment of oral diseases, there has been considerable advancement in technology. As a result, numerous laser systems are currently available for oral use. Neodymium:Yttrium–Aluminum:Garnet (Nd:YAG), carbon dioxide (CO_2) laser and the semiconductor Diode lasers have already been approved by the US Food and Drug Administration for soft tissue treatment in oral cavity. The Erbium:YAG (Er:YAG) laser was approved in 1997 for hard tissue treatment in dentistry and recent studies have reported positive results. This suggests that the Er:YAG laser system is a promising apparatus, which will be able to revolutionize and improve dental practice, in particular periodontal treatment. In this mini-review, we would like to describe the positive characteristics of the Er:YAG laser which indicate its potential as a new treatment modality in periodontics.

Materials and methods: Recent findings are summarized briefly to evaluate the potential of the Er:YAG laser for clinical application in periodontics.

Results: The Er:YAG laser possesses suitable characteristics for oral soft and hard tissue ablation. Recently, it has been applied for effective elimination of granulation tissue, gingival melanin pigmentation and gingival discoloration. Contouring and cutting of bone with minimal damage and even or faster healing can also be performed with this laser. In addition, irradiation with the Er:YAG laser has a bactericidal effect with reduction of lipopolysaccharide, high ability of plaque and calculus removal, with the effect limited to a very thin layer of the surface and is effective for implant maintenance.

Conclusion: The Er:YAG laser seems to be an effective tool for periodontal therapy, however, further clinical and basic investigations are required to confirm its clinical application.

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The use of lasers for therapy has become very common in the medical field. It is considered the standard of care for therapy particularly in ophthalmology (1), otolaryngology (2) and dermatology (3). The first device, the ruby laser, was created by Maiman in 1960 (4) and it was introduced for use in dentistry by Stern and Sognnaes (5) and Goldman *et al.* in 1964 (6). In view of the recent advances and development of different delivery systems with a wide range of laser wavelengths, researchers postulate that lasers could be applied for dental treatment. However, dental practitioners are yet to understand the different characteristics of various lasers clearly.

Lasers, in general, consist of an active medium and a pumping source enclosed in an optical cavity. The pumping source pumps the active medium from its ground state (inactive state) to an excited state. Very intense flashes of light or electrical discharges pump the lasing medium and create a large collection of atoms in the excited

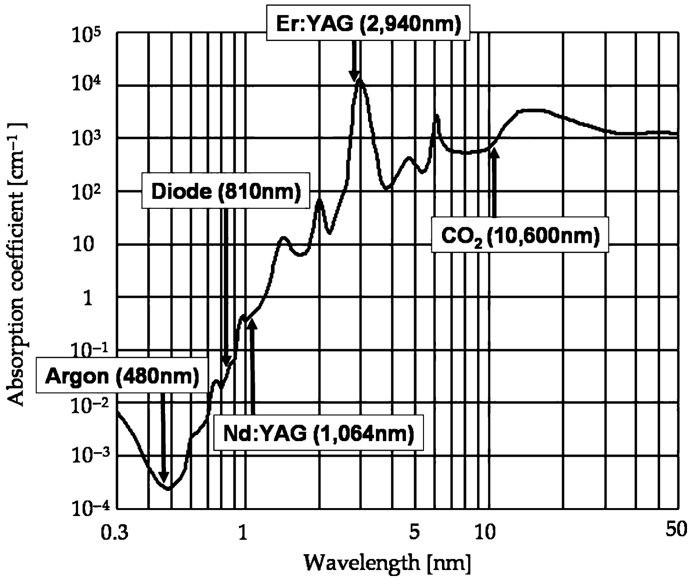

Fig. 1. Different water absorption of various lasers, such as Argon, Semi-conductor Diode, Nd:YAG, CO_2 and Er:YAG. The Er:YAG laser, with wavelength 2940 nm, has the best absorption coefficient of water among the lasers systems.

state for the laser to work efficiently. Based on the active lasing medium, it can be a container of gas or a solid crystal rod. The gas-active medium lasers available in dentistry today are argon and CO_2 lasers. In solid-state lasers, a garnet crystal made from yttrium and aluminum is commonly used and these are known as YAG lasers.

In 1964, the Neodymium:YAG (Nd:YAG) laser was introduced by Geusic (7). This laser has an active medium that is a solid garnet crystal made from yttrium and aluminum uniformly doped with small amounts of neodymium. The emission wavelength is 1064 nm, in the near-infrared spectrum as shown in Fig. 1. The wavelength of Nd:YAG penetrates into water to a depth of 60 mm and the energy is scattered in soft tissues rather than being absorbed on the tissue surface. It is highly absorbed by black color and therefore, this laser is commonly used for cutting and coagulation of oral soft tissues with good hemostasis. However, due to its scattering effect, it is difficult to judge the depth of penetration of this laser (8). In addition, preparation of cavities in a tooth is impossible with this laser (8).

In 1975, Zharikov introduced the Erbium:YAG (Er:YAG) laser (9). The active medium of this laser is a solid crystal of yttrium–aluminum–garnet that is doped with erbium. The Er:YAG laser has characteristics completely different from Nd:YAG laser. The wavelength of the Er:YAG laser lies near the boundary of the near-infrared and mid-infrared, invisible portion of the spectrum. The coherent and collimated light of this laser with a wavelength of 2940 nm is highly absorbed in water (10). Theoretically, its absorption coefficient of water is 10 times higher than the CO_2 laser (wavelength 10,600 nm) and 15,000–20,000 times higher than the Nd:YAG laser (wavelength 1064 nm) (10, 11) as shown in Fig. 1. Due to its high absorption by water, less tissue degeneration with very thin surface interaction occurs after Er:YAG laser irradiation. Also, the temperature rise is minimal in the presence of water irrigation, which makes hard tissue preparations, caries removal and scaling treatment easily possible with this laser, without any carbonization (12–15). Due to its sterilization and soft tissue ablation characteristics, this laser can be used as a smooth laser knife, even though it is not capable of providing adequate hemostasis. Table 1 shows the different characteristics of Nd:YAG and Er:YAG lasers.

Table 1. Different characteristics of Erbium and Neodymium:YAG lasers

	Erbium:YAG laser	Neodymium:YAG laser
Wavelength	2940 nm infrared	1060 nm near infrared
Body interaction	Surface absorption type	Deep penetration type
Ablation type	Photo-mechanical ablation (Disintegration by heat expanded distortion of water)	Photo-thermal ablation (Ablation by heat burning)
Characteristics	Very thin surface interaction	The laser penetrates into water to a depth of 60 mm
	Absorbance rate is about 10 times higher than that of CO_2 laser	Scattering in soft tissues
	Less temperature rise with water irrigation	Causing ‘cooking effect’
	Less tissue degeneration	Vaporizing and removing tissue
	Hard tissue preparation	Selective absorption in dark substance
Advantage	Applicable to both hard and soft tissues	Best suited for primary coagulative properties
	No carbonization	Selective and fine cutting with contact probes
	Easy to perform scaling and caries treatment	Optically transmittable fiber
	Sterilization effect	
	Smooth laser knife	
	Optically transmittable fiber	
Disadvantage	Less hemostasis	Difficulty in judging the depth of penetration
		Impossible to prepare cavities in teeth

Applications of lasers in oral soft and hard tissues

Various reports have confirmed the safety and efficacy of CO_2 and Nd:YAG lasers, which are the most commonly used lasers in soft tissue application (16–19). However, when these lasers are applied to dental hard tissues, thermal side-effects have been a major problem. The thermal effect of the laser beam is based on the absorption of radiation by tissue and subsequent transformation of laser energy into heat (20, 21). Heat generation during laser irradiation often causes carbonization, melting and cracking of the tooth structure, and inflammation and necrosis of the pulp (21, 22). The application of the CO_2 or Nd:YAG laser for hard tissue treatment tends to result in deleterious effects, such as carbonization, melting and denaturation of proteins, with consequent formation of toxic substances as well as compositional changes on the irradiated tissues (20, 21). However the Er:YAG laser showed satisfactory results for hard tissue ablation, due to its characteristic wavelength that is well absorbed by water. Hibst and Keller (23) and then Sasaki *et al.* (24) have explained the theory of 'microexplosions' regarding the mechanism for hard tissue ablation. According to this theory, the energy is selectively absorbed in water and other hydrous organic contents. Some vapor such as steam builds up internal pressure until explosive destruction of inorganic substance occurs before the melting point is reached. Therefore, the effects of Er:YAG laser are probably not explained completely by thermal effects, but by the microexplosions associated with water evaporation within the hard tissue.

Pioneer works with Erbium:YAG laser

Hibst *et al.* was the first to report the use of the Er:YAG laser in 1988 (25) for ablation of dental hard tissues. During the same period, several researchers examined the effectiveness of this laser for hard tissue ablation (23, 26–29). In 1989, Paghdiwala prepared holes in enamel and dentin with low energy and without water cooling, which showed that the Er:YAG laser was capable of ablating dental hard tissues (26). Hibst and Keller reported effective removal of enamel and dentin by the Er:YAG laser after measuring the depth and diameter of laser-drilled holes (23). Kayano *et al.* suggested that the Er:YAG laser could be used for cavity preparation (27, 29). In the same year, Keller and Hibst demonstrated in extracted teeth that the enamel and dentin removal could be performed effectively with minimal thermal damage to the adjacent tissues (28). Several studies showed that the Er:YAG laser is effective and safe for caries removal (13, 30–33). In 1995, Kumazaki reported effective caries removal by Er:YAG laser (30). In a scanning electron microscopic (SEM) study, Ishikawa *et al.* observed effective removal of softened carious dentine by Er:YAG laser ablation, with no smear layer on the irradiated area (32). Pelagalli *et al.* also demonstrated by SEM that the resultant surface morphology and ability to remove caries were similar after treatment with Er:YAG laser and mechanical drill (33). Furthermore, other studies reported effective caries removal by this laser, with minimal thermal damage to the adjacent dentin (13, 31).

Periodontal scaling with Er:YAG laser

Scaling and root planing is the traditional method of controlling subgingival microflora for management of periodontitis. The objectives of subgingival debridement are to remove not only the adherent and unattached bacterial plaque, but also deposits of calculus. However, removal of calculus using conventional hand instruments has been reported to be incomplete and rather time consuming (34). In order to improve the effectiveness and efficiency of root surface debridement, various devices such as sonic and ultrasonic scalers, and more recently lasers have been used. Numerous studies have demonstrated that sonic or ultrasonic instrumentation, when compared with manual instrumentation, results in equal or superior treatment outcomes (14, 35). However, sometimes the root anatomy renders it difficult to achieve a biologically compatible root surface (36). Regardless of the instrument of choice, interproximal areas, furcas, the cemento–enamel junction and multi-rooted teeth are most likely to exhibit residual plaque and calculus following treatment (37). Considering these difficulties in performing successful periodontal treatment, Er:YAG laser scaling was recently introduced as an alternative to conventional scaling procedures (12, 14, 38, 39). In an *in vitro* study, Aoki *et al.* showed the efficiency of Er:YAG to remove subgingival calculus at the energy level of approximately 30 mJ/pulse under water irrigation and suggested that this laser could be applied clinically for subgingival scaling (12). Effective calculus removal in an extracted tooth is shown in Fig. 2. In another study, the effectiveness of Er:YAG laser scaling and also the morphological and histological changes of the laser-scaled root were evaluated. Characteristic changes of the root surface after irradiation were demonstrated by histological and SEM examination and laser scaling provided a level of calculus removal that was similar to that provided by the ultrasonic scaling (14). Several studies described the morphological change of root surface after Er:YAG laser treatment (12, 14, 39–46). The results of our previous study have shown that in addition to subgingival calculus, the superficial layers of contaminated cementum could be removed with the Er:YAG laser (12, 14, 47). Histological and SEM examinations of the root surface alterations showed partial loss of cementum, resulting from cementum ablation, and sometimes loss of dentine, but no cracks or thermal side-effects such as melting and microfracture, which are usually observed after CO_2 or Nd:YAG laser irradiation (14, 40, 41, 47). Some researchers are conclusive in the occurrence of charring and melting on the root surface after Nd:YAG laser irradiation (40, 48–50). The CO_2 lasers were reported to induce melting, resolidification and

Fig. 2. Removal of subgingival calculus using Er:YAG laser. (a) Extracted tooth with a band of subgingival calculus before laser treatment. (b) After Er:YAG laser scaling at 40 mJ/pulse and 10 Hz with water spray using a conventional cylindrical tip. Effective removal of subgingival calculus with no thermal alteration of the root surface.

microfracture of the surfaces (21, 40). The surface roughness caused by Er:YAG irradiation is demonstrated in several studies (12, 14, 51–54). However, there is evidence that this surface roughness itself has no negative influence on the clinical healing following periodontal treatment (55).

Bactericidal and detoxification activity of Er:YAG laser

The Er:YAG laser irradiation has been reported to exhibit high bactericidal properties (56–58). Although mechanical periodontal treatment alone improves clinical conditions, conventional methods for treatment of periodontal disease are not equally effective in eliminating all types of bacteria. *Actinobacillus actinomycetemcomitans*, a periodontopathogen important in the development of periodontal disease, is known to be difficult to eliminate with usual mechanical means (59, 60). These limitations have led to a shift in emphasis from a purely mechanical approach to other methods, which include the use of adjunctive antimicrobial procedures. Ando *et al.* initially reported the bactericidal effect of Er:YAG laser against periodontopathic bacteria (56). Also, it has been demonstrated that bactericidal effects could be achieved in dental root canals (61) and implant surfaces by Er:YAG laser irradiation (58). Furthermore, this laser is believed not only to eliminate bacteria but also to inactivate bacterial toxins diffused within root cementum (62, 63). Yamaguchi *et al.* suggested that Er:YAG laser irradiation effectively and rapidly eliminated most of the lipopolysaccharide on the extracted root surfaces and might be useful for root conditioning in periodontal therapy (62). It was also reported that no smear layer was produced on the Er:YAG laser-irradiated surface (32), in contrast to manual scaling and root planing, after which a smear layer is often observed (64). This suggests a possible advantage of laser periodontal therapy (47), because the presence of smear layer has been reported to be detrimental to periodontal tissue healing by potentially inhibiting or slowing reattachment of cells to the root surface (65, 66). Also, root cementum and dentin treated with the Er:YAG laser under water coolant was free of toxic by-products such as cyanate (NCO^-) and cyanamide (NCN^{-2}), which were observed on surfaces irradiated by CO_2 laser (46). These toxic substances might inhibit reattachment and migration of fibroblasts. It indicates that extremely high temperatures, as reported to occur during CO_2 laser irradiation, do not occur during Er:YAG laser irradiation with water irrigation (46). Gaspirc *et al.* showed that the Er:YAG laser alters the morphology and increases the diffusion process of the root surface without any thermal damage, whereas Nd:YAG alters the chemical structure (44).

Clinical studies with Er:YAG laser

Several clinical studies have reported the application of Er:YAG laser for periodontal therapy (38, 45, 55, 67). Watanabe *et al.* demonstrated efficient subgingival calculus removal with no side-effects and uneventful reduction of pocket after Er:YAG scaling (55). Schwarz *et al.* reported that equal or better results were observed at six months after laser treatment of periodontal pockets, compared to conventional mechanical debridement using hand scalers and found significantly higher reduction of bleeding on probing scores and improvements in clinical attachment level after laser treatment (38). Schwarz *et al.* also demonstrated that non-surgical periodontal treatment with the laser alone and a combination of Er:YAG laser and scaling and root planing using hand instruments may result in clinically and statistically significant improvements in the clinical parameters, with no difference between the two therapies, 12 months after treatment (67). It may be assumed from the results from these controlled clinical trials and case report studies that the use of the Er:YAG laser for non-surgical periodontal treatment may be safe, because the minimally invasive device allow instrumentation of very deep and narrow pockets without causing major trauma to hard and soft tissues (38, 68), resulting in a significant gain of clinical attachment level (38, 55, 67). Long-term follow-up results reported by Schwarz *et al.* concluded that the clinical improvements could be maintained over

2 years following non-surgical periodontal treatment (69).

Risks and disadvantages of Er:YAG laser

While using Er:YAG laser, the operator must be aware of the possible risks involved and caution must be exercised to minimize these risks. Use of inappropriate power settings, especially high energy, for irradiation of root surfaces is a major risk. During laser irradiation, the power settings play a significant role and must be regulated appropriately in order to avoid detrimental effects to the irradiated tissue (70). An *in vitro* study showed that surfaces treated with Er:YAG laser at 100 mJ/pulse exhibited delayed growth and adhesion of gingival cells than surfaces treated with 60 mJ/pulse (71). Another histological and SEM study involving two different laser tips showed an increase in the incidence and depth of craters created on lased root surfaces, in comparison with conventionally scaled surface (72). However, the calculated energy density at the tip of the contact probe used in this study was relatively high and inappropriate for root surfaces. It should be pointed out that the efficacy of laser scaling might be improved by using different variables, such as pulse repetition rates and pulse duration and not only increasing the energy output (70). Furthermore, another factor limiting the rate of laser ablation of dental hard tissue is the risk of excessive heat accumulation within the tooth. Excessive heat may result in undesirable damage to the pulp and the root surface (73). Some degree of heat generation is inevitable during laser scaling using the Er:YAG laser. Thermal alteration of the root surface after laser irradiation has been reported by some researchers (54, 72, 74). However, most recent reports propose the use of water as a coolant during Er:YAG laser irradiation to avoid any harmful effects to the irradiated tissues (14, 40, 46).

The use of water spray minimizes the heat generation by cooling the irradiated area and absorbing excessive laser energy (12, 14, 47, 54, 75). Water irrigation effectively prevented thermal damage and did not cause major compositional or chemically deleterious changes in either root cementum or dentin after irradiation (46). Longer intervals between pulses and an air stream also aid in keeping the target cooler by avoiding the transfer of heat to the surrounding tissue (73).

More studies should be performed to find the optimal power settings for safe irradiation, without any harmful effects to the root surface or surrounding tissue. Other variables such as pulse repetition rates and pulse

Fig. 3. Removal of gingival melanin hyperpigmentation using Er:YAG laser. (a) Gingival tissue with a band of pigmentation before surgery. (b) Er:YAG laser irradiation at 27 mJ/pulse and 20–30 Hz with water spray under topical anesthesia for removal of melanin hyperpigmentation. (c) Immediately after surgery. Effective removal of pigmented gingival tissue without major thermal damages such as carbonization and coagulation. (d) Favorable healing of the treated site at 1 week after the procedure.

duration have to be regulated as well, to obtain the desired effect. The power energy output at the tip must not be high, preferably not more than 60 mJ, to avoid such undesirable effects. Also, water irrigation is essential to eliminate thermal side-effects on the root surface.

Other clinical applications of the Er:YAG laser

Gingival melanin and gingival discoloration removal

Complaints of 'black gums' are common, and depigmentation is usually performed for esthetic reasons. The efficiency of melanin hyperpigmentation removal with laser was evaluated by several researchers (76–79). The Er:YAG laser is capable of excellent soft tissue ablation, which makes it suitable for this kind of pigmentation removal (15). In our previous study, the width of the thermally changed layer in gingival connective tissue was 5–20 μm after Er:YAG laser melanin removal in dogs (80). Clinically results indicated safe and effective melanin pigmentation ablation (81, 82) as shown in Fig. 3. Furthermore, the Er:YAG laser was utilized for removal of abnormal gingival discoloration, namely metal tattoos. It is suspected that dental treatment procedures or restorative materials cause this kind of discoloration. A recent report indicated that this kind of discolored gingiva contained silver sulfate, tin sulfate, and pieces of iron, as observed by electron probe microscopy (83). Apparently, the iron must have originated from cutting steel instruments, since it is not a component of silver alloy and without surgical removal of the gingival tissues containing the fragments, the discoloration will still remain (83). Effective removal of discolored gingiva together with metal fragments was reported possible using an Er:YAG laser, with no pain or gingival recession (84), as shown in Fig. 4.

Bone tissue application

The application of the Er:YAG laser on bone in oral and periodontal surgery is not very common and there are few reports regarding the use of this laser for bone ablation (24, 53, 85–88). Nelson *et al.* reported that the Er:YAG laser ablated bone effectively with minimal thermal damage to the adjacent tissues (85). The ability of bone tissue removal with minimal chemical and morphological changes to the irradiated and surrounding surfaces was demonstrated previously. A typical irregular pattern, which consisted of biological apatites surrounded by organic matrix, was observed in the irradiated bone and this

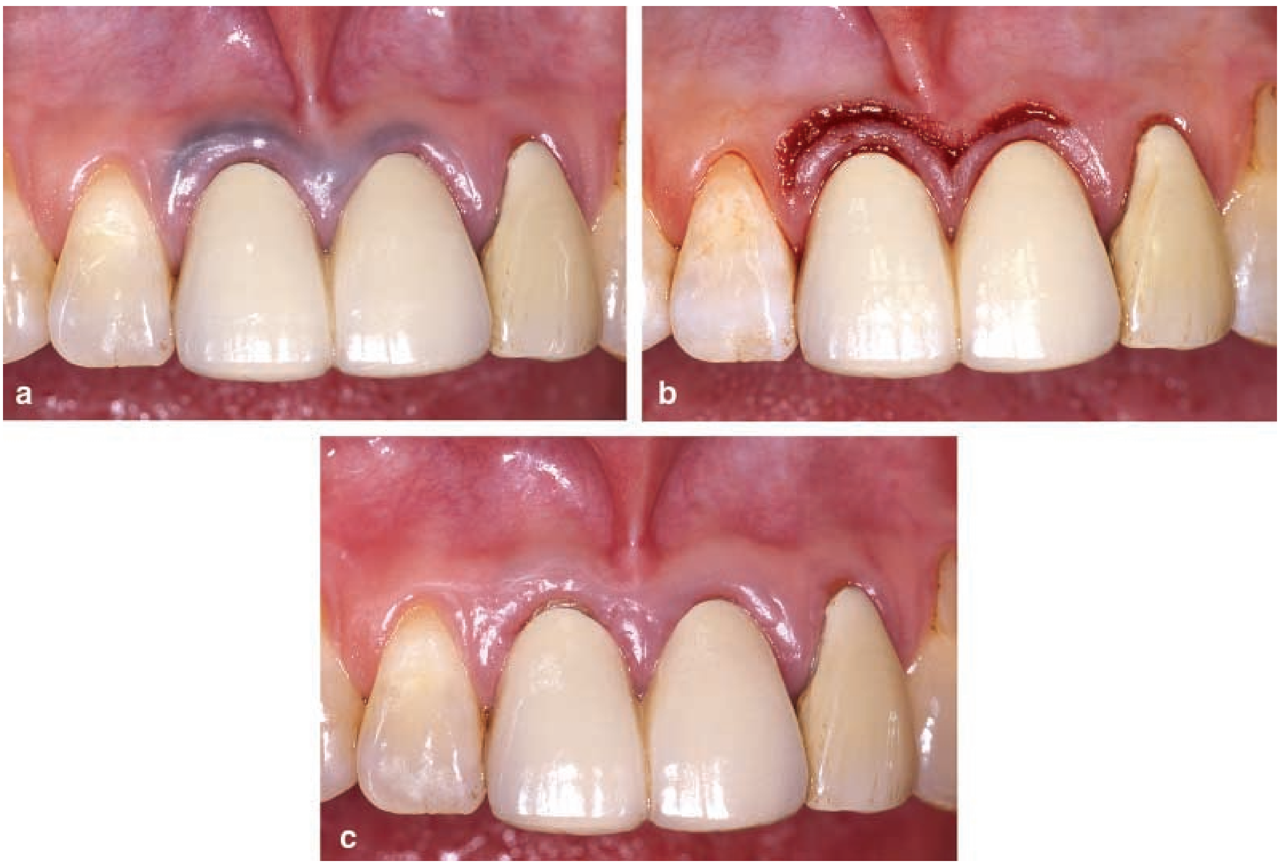

Fig. 4. Removal of abnormal gingival discoloration, namely metal tattoos, using an Er:YAG laser in combination with a surgical microscope. (a) Metal tattoos at marginal area of central incisors before the treatment. (b) Treatment site immediately after irradiation at 40 mJ/pulse and 30 Hz with water spray under local anesthesia. (c) Four weeks after removal. Effective removal of discolored gingiva without any recession.

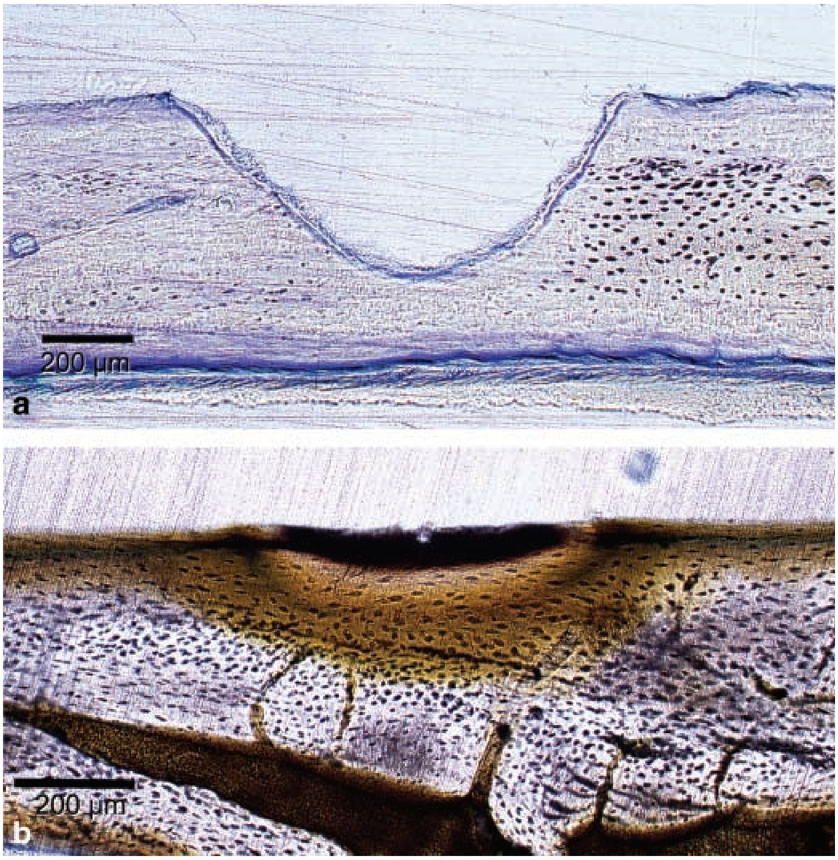

Fig. 5. Histological observation by light microscopy of bone surface after laser irradiation. (a) Histological photomicrograph after Er:YAG laser irradiation at 100 mJ/pulse and 10 Hz (1 W) under water irrigation. Groove-like appearance and thin changed layer of irradiated bone surface. (b) Histological photomicrograph after CO_2 laser irradiation at 1 W. Extensive thermal effect produced on bone surface. A dark carbonized layer is evident. [From Sasaki *et al.* Ultrastructural analysis of bone tissue irradiated by Er:YAG laser. *Lasers in Surgery and Medicine* 2002; 31: 322–332. With permission. LASERS IN SURGERY AND MEDICINE © copyright (2002) Wiley-Liss, Inc.]

may have aided in uneventful healing (24). Lewandrowski *et al.* reported that the healing rate following Er:-YAG laser irradiation may be equivalent or even faster than that following bur drilling (86). Sasaki *et al.* showed, histologically, a thin altered layer produced by Er:YAG laser on the irradiated rat calvaria bone surface. The irregular bone morphology after irradiation and absence of toxic substances may have promoted the adhesion of plasma proteins during the initial stages of healing. On the other hand, the bone ablated using CO_2 laser showed extensive thermal effects (Fig. 5) (24). In another study from our research group, Pourzarandian *et al.* demonstrated that the initial bone healing following Er:YAG laser irradiation occurred faster than that after mechanical bur drilling and CO_2 laser irradiation in rats, observed by light and transmission electron microscopy (88). This laser system has been demonstrated to be useful for bone ablation (Fig. 6) and osseous recontouring during periodontal surgery. There is a possibility that the bone is biostimulated after Er:YAG laser irradiation, but further experiments have to be carried out to elucidate the exact mechanism of Er:YAG laser irradiation in bone tissue.

Granulation tissue removal

In 1995, Williams *et al.* used CO_2 laser for removal of granulation tissue and connective tissue from interproximal craters (89). Sasaki *et al.* suggested the possibility of granulation tissue removal by Er:YAG laser during periodontal flap surgery (53). Effective granulation tissue removal from vertical bone defects by this laser is shown in Fig. 7. Although it may be a promising tool for granulation tissue removal in periodontal pocket sites, there appear to be no clinical studies using Er:YAG laser. Further research is required to show efficacy of granulation tissue removal without any thermal damage to the adjacent surrounding tissue including alveolar bone and root surfaces.

Implant maintenance

The Er:YAG laser was also proposed for implant maintenance, taking advantage of its bactericidal effect, technical simplicity and absence of postoperative pain and edema (90, 91). Peri-implant infection results in inflammation of the surrounding soft tissues and can induce a breakdown of the implant-supporting bone. It is

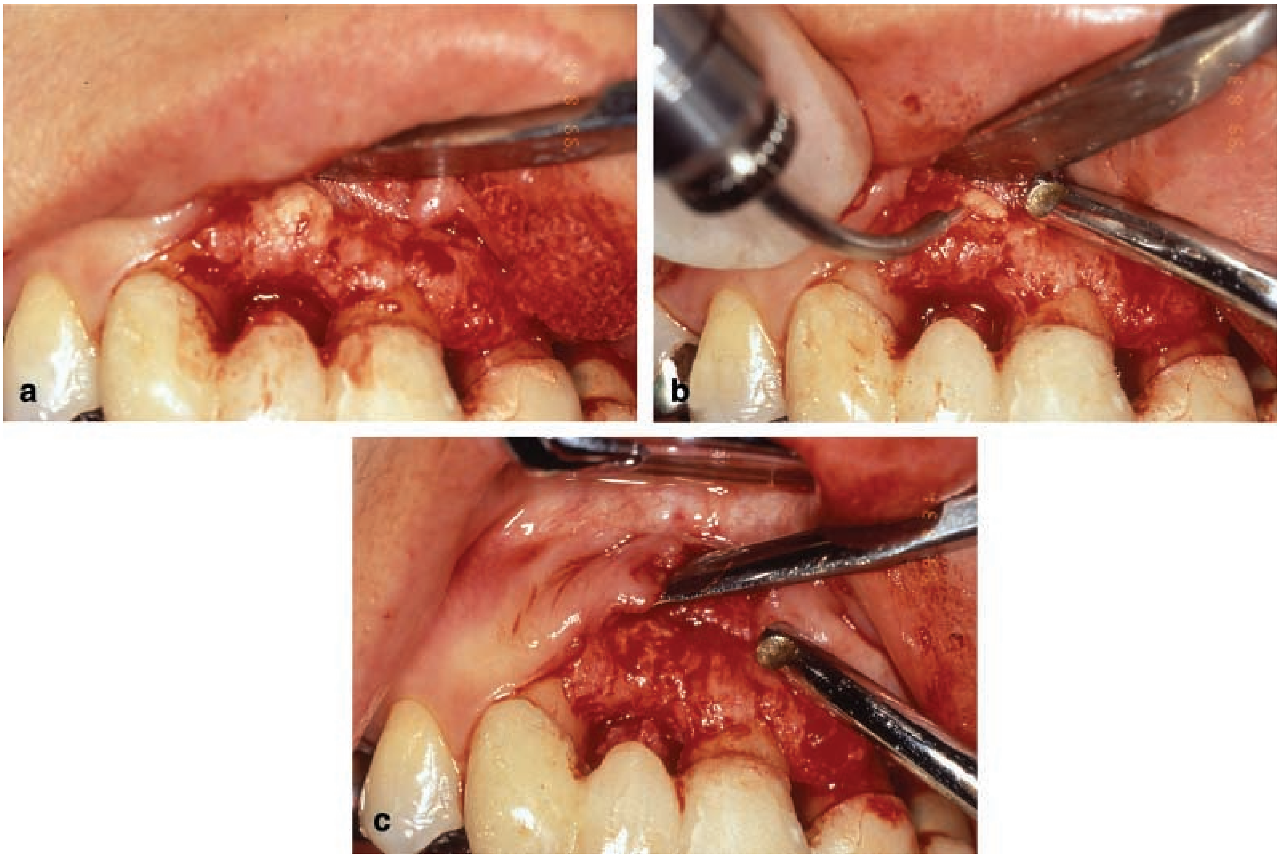

Fig. 6. Bone surgery using Er:YAG laser. (a) Exostosis before resection. (b) Exostosis removal by Er:YAG laser irradiation at 100 mJ/pulse and 10 Hz with saline water spray. (c) Site immediately after effective removal of exostosis.

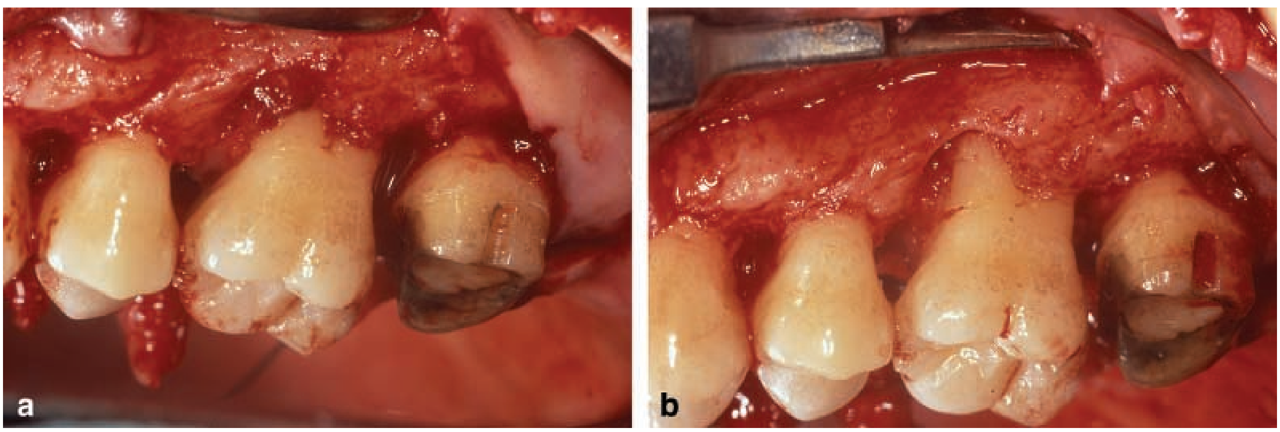

Fig. 7. Granulation tissue debridement using Er:YAG laser with water irrigation during flap operation. (a) Presence of granulation tissues in vertical bone defects. (b) Effective granulation tissue removal from vertical bone defects after Er:YAG laser debridement at 100 mJ/pulse and 10 Hz with saline water spray.

associated with the presence of a subgingival microflora, which is quite similar to that in periodontal pockets and contains a large variety of Gram-negative anaerobic bacteria (92). Kreisler *et al.* demonstrated *in vitro* the high bactericidal potential of Er:YAG laser on titanium implants with different surface characteristics (58). Matsuyama *et al.* performed debridement of implant abutment surface by this laser and reported effective removal of plaque and calculus without injury to the surface (93). Also, Kreisler *et al.* observed nonexcessive heat generation on the implant surfaces and effective decontamination by means of the Er:YAG laser (94). *In vivo*, Schwarz *et al.* demonstrated the effectiveness of this laser treatment to remove subgingival calculus from surfaces of implant fixtures without any thermal damage (95).

Summary

In summary, laser treatment is expected to serve as an alternative or adjunctive to conventional mechanical therapy in periodontics due to various advantages, such as easy handling, short treatment time, hemostasis and decontamination and sterilization effects. Among all the lasers, Er:YAG laser possesses characteristics suitable for oral treatment, due to its dual ability to ablate soft and hard tissues with minimal damage. Also, its bactericidal effect with elimination of lipopolysaccharide, ability to easily remove plaque and calculus, irradiation effect limited to an ultra-thin layer of tissue, even or faster bone repair after irradiation than conventional bur drilling, and effective ability for implant maintenance, make it a promising tool for periodontal treatment. However, to obtain the desired success of periodontal treatment without damage of the surrounding tissue, the appropriate laser parameters, such as power energy, energy density and time of irradiation have to be used. Even though successful experimental results have been reported so far with the Er:YAG laser, further studies are required to better understand the effects on biological tissues for its safe and effective application during periodontal therapy. Thus, randomized controlled clinical trials and more basic studies have to be encouraged and performed to determine the most optimal and safest parameters for laser treatment. The dental practitioners need to be aware of the risks involved in laser irradiation, and properly instructed regarding the safe and effective use of this laser. In conclusion, the Er:YAG laser shows promise as an effective tool for periodontal therapy, but further research is required to confirm its clinical application.

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