State of the Art in Lasers for Dentistry

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ABSTRACT:
Lasers have been used in dentistry since 1964. The idea was to be able to treat both soft tissues and hard tissues, including bone, without direct contact, vibrations and pain. Since the early 90's lasers have been applied in a wide variety of dental application areas. In this paper Prof. dr. Norbert Gutknecht, President of the German Society for Laser Dentistry (DGL), provides an overview, discusses laser applications and presents possible uses of lasers in various dental application areas.

Key words: dental lasers, Er:YAG, Nd:YAG, diode, CO_2, periodontology, endodontics, implantology, peri-implantitis, soft tissue surgery

INTRODUCTION

Each laser can be distinguished by its own, specific characteristics. The most important and principle characteristic is wavelength, which defines the position of the laser in the electromagnetic spectrum. Laser-tissue interaction is defined by the laser energy that enters the tissue. Here the absorption of the laser beam's energy plays an important role and is illustrated by the absorption spectrum for each laser wavelength in the targeted tissue and/or tissue components. Apart from wavelength and absorption, reflection and transmission also play a role in laser-tissue interaction. Transmission is the degree to which the laser's energy is able to penetrate into the tissue.

ENDODONTICS

The use of lasers in endodontics is aimed at eradicating germs in the root channel, especially in the lateral dentinal tubulus (necrotic, gangrenous pulp in the corona and root). This requires a wavelength that shows high transmission through hydroxyapatite and water. The absorption curves show that Nd:YAG lasers, and in particular pulsed Nd:YAG lasers, are first-choice for this application. Nd:YAG lasers show the best results in transmission and germ reduction measurements. Even at penetration depths exceeding 1.000µm, 85% germ reduction is accomplished. The 810nm diode laser is the second choice laser source. Micro-biological studies have shown that this source provides the second highest germ reduction, approximately 63%. This is nevertheless significantly lower than with Nd:YAG lasers. 980nm diode lasers may also be an option although high transmission is achieved due to its higher absorption in water. This explains why this laser source, especially at a depth of 1.000µm, can only achieve 30% to 40% germ reduction.

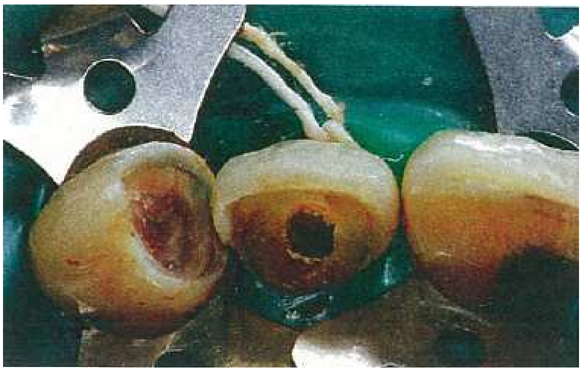

Fig. 1: Representation of the channel entrance of tooth 12

Fig. 2: Nd:YAG fiber inserted the root canal of tooth 24

All other wavelengths such as Er:YAG, Er,Cr:YSGG and CO_2 lasers are not applicable in endodontics. Their absorption in hydroxyapatite and water is so high that germ reduction would predominantly only take place in the main canal, although germ reduction through thermal effects can still be detected in the lateral dentinal tubuli up to depths of 300µm to 400µm. These wavelengths are not very suitable for endodontic treatments. Er:YAG and Er,Cr:YSGG lasers can however be successfully used to remove organic tissue and smearlayers.

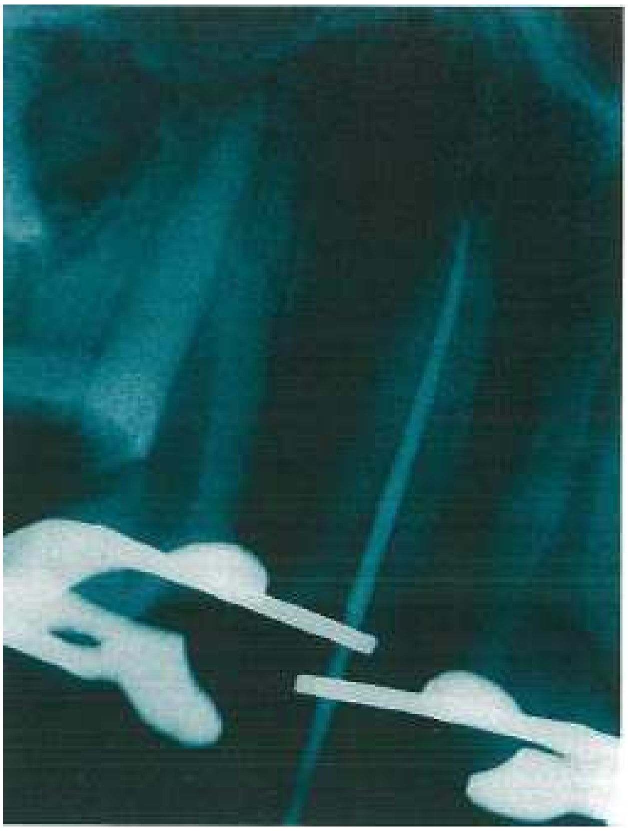

Fig. 3: Master point image of tooth 12

Fig. 4: Situation after root filling of tooth 12.

LASER-ASSISTED PERIODONTICS

In the periodontics the closed curettage, with a probe depth of 5mm to 6mm, and the open curettage, with probe depths over 6mm, are differentiated.

In cases where periodontal disease is present and it is preferred to perform a closed curettage, lasers can be used for germ reduction after having completed pretreatment and concrement removal using conventional methods. In closed curettage procedures only lasers with wavelengths that do not damage adjacent tissue can be used, while these lasers must also show good interaction with soft tissue and the germ spectrum present in the periodontal pocket. Pulsed Nd:YAG lasers fulfill both requirements; they eradicate germs that have accumulated on the hard tissue surface and, because Nd:YAG lasers interact with pigmented surfaces, reduce germs in periodontal pockets extremely well. 96% of germs in periodontal pockets are pigmented and can thus be selectively eradicated by Nd:YAG lasers. Nd:YAG lasers' interaction with soft tissue is relatively gentle, i.e. it does not involve any substantial soft tissue damage or removal. They provide a relatively conservative procedure and are associated with rapid wound healing. With Nd:YAG laser procedures, anesthesia is required in less than 50% of cases.

Alternatively 810nm diode lasers show very good interaction with pigmented tissues and thus also induce very high germ reduction, which is similar to that of Nd:YAG lasers. However the interaction with soft tissue is higher and thus the thermal effects and damage to the surrounding tissues is more pronounced. This means that treatments with the 810nm diode laser cannot be performed without anesthesia.

980nm diode lasers can also be considered for laser-assisted closed curettage procedures. Their high absorption and interaction with water in the periodontal pockets lead to a high germ reduction. However, their lower interaction with hemoglobin increases the thermal effect in the tissue. If this laser source is not applied with extreme caution in periodontic procedures, surface necroses may be caused. In addition, relatively high tissue temperatures are reached and anesthesia is necessary.

In laser-assisted open curettage procedures Er:YAG lasers are clearly and unambiguously first choice. In special cases a CO_2-laser (10.6µm; cw=continuous wave) may be indicated. The Er:YAG laser device of choice for open curettage procedures is a system that, above all, should allow a wide selection of pulse duration and repetition rate settings. These features will allow extremely good inter-radicular and interdental cleaning to be carried out, while bone tissue can be very efficiently freed from infected soft tissue. Moreover, a very fine retentive pattern on the root and bone surfaces can be created, which is of great importance for reattachment.

If the Er:YAG laser device allows the practitioner to vary the pulse duration during the open curettage procedure, then short pulses from 60μs to 120μs are recommended. At these settings thermal effects are extremely low and thus thermal damage is not to be expected. Post-operative bleeding is minimal, so that problem-free wound healing will occur. Er,Cr:YSGG lasers also belong to the category of erbium lasers, and can be used in open curettage procedures. However, it must be noted that their absorption in water is exponentially two to three times lower than that of Er:YAG lasers. Their thermal effects on the tissue are much higher if not administered correctly.

IMPLANTOLOGY

There are several wavelength options to uncover implants. The first wavelength ever used to uncover implants was the 10.6μm CO_2-laser, although that tissue surface carbonization was a small disadvantage. As an alternative the 810nm and 980nm diode lasers can be used, although the thermally damaged areas are larger than with CO_2-lasers. Very good results can be achieved with Er:YAG lasers, if the laser device offers the possibility to vary pulse duration or if special surgical tips can be used. With pulse duration settings between 800 μs and 1000μs, tissue interaction leads to higher thermal effects. This enables smaller vessels to be sealed without leaving areas of carbonized or necrotic tissue. While a tendency for light bleeding through larger vessels remains, this in fact leads to faster wound healing, less post-operative swelling and less inflammation in the wound area, compared to diode and CO_2-lasers. Considering the physiological aspects of wound healing, Er:YAG lasers are the ideal modality to uncover implants. Implant damage does not occur with CO_2, Er:YAG and Er,Cr:YSGG lasers because their wavelengths have a high reflection potential and thus hardly any absorption in metallic surfaces. Pulsed Nd:YAG lasers are unsuitable to uncover implants.

PERI-IMPLANTITIS

The treatment of peri-implantitis is performed similarly to closed or open curettages in periodontics. Both Nd:YAG and diode lasers have their application areas in this field. Most studies on the treatment of peri-implantitis are based on 810nm diode lasers.

The best procedure to treat a large peri-implantitis defect is however uncovering the implant that has been affected by inflammation. Only under such visibility conditions is it possible to completely remove the granulation tissue and infected tissue.

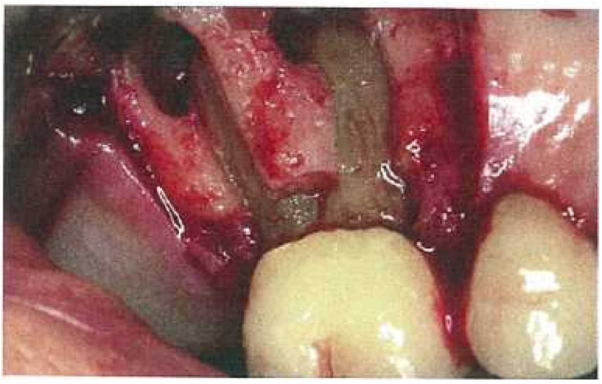

Fig. 5: Removal of the closed bone cover with the Er:YAG laser to present the root point.

Fig. 6: Resection of the root point with the Er:YAG laser.

Fig. 7: Removal of the granulated tissue with the Er:YAG laser; subsequent germ reduction in the depth of the bone or the resection cavity performed using the Nd:YAG laser.

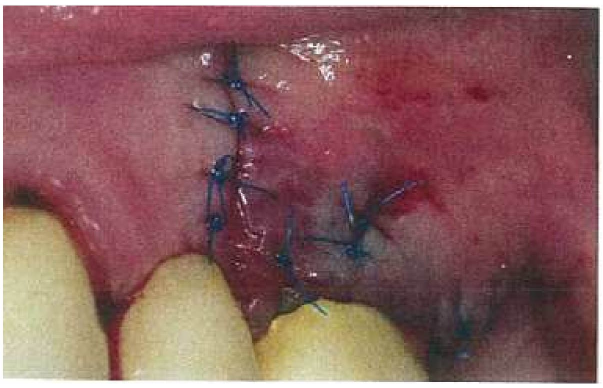

Fig. 8: Situation immediately after completion of the

root point resection..

More importantly, this is the only way that infected tissue in the implant's contortions can be reached. Short pulsed Er:YAG lasers are the ideal modality. The shorter the pulses, the more efficiently the granulation tissue can be removed to clean the implant surface without problems. With pulse durations between 60µs and 200µs and very low energy settings, the infected tissue can be cleared away very efficiently. Similar good results have also been achieved with Er,Cr:YSGG lasers.

SOFT TISSUE SURGERY

For soft tissue cutting, e.g. abscess incisions, where a sterile cut with as little bleeding as possible is required, both the 810nm and 980nm diode lasers, as well as the pulsed Nd:YAG laser can be used.

Surgical procedures in soft tissue require a cautious approach. 810nm diode and CO_2 lasers are very well suited for frenectomies (operations on the frenula of the lips, cheeks or tongue). Caution is required when using Nd:YAG and 980 nm diode lasers because the higher thermal effect of these wavelengths (< 100µs) can very often cause necroses.

Er:YAG laser systems that allow very long pulse duration settings (> 700µs) are also suitable for frenectomies and soft tissue surgical procedures in general. Er,Cr:YSGG laser and basic Er:YAG laser systems can also be used in soft tissue surgery, but only with special surgical tips.

The difference between CO_2 and long pulse Er:YAG lasers lies in their differing absorption coefficients. Er:YAG lasers are much more strongly absorbed in the water; i.e. the soft tissue is already isolated through the laser's interaction with water in the cells, without requiring any high thermal effect. Micro-ruptures occur and with this bleeding follows. CO_2 lasers on the other hand, show very high absorption on the tissue surface. Due to these lasers' different mode of operation – mostly continuous wave operation – the thermal effects are more pronounced on the upper tissue layers and less in the deeper tissue layers than with Er:YAG lasers. This leaves a carbonized upper tissue layer although bleeding is less pronounced. With very long pulse durations, long pulse Er:YAG laser systems can provide a very good alternative, as the thermal effect is higher and thus smaller vessels are sealed. Bleeding is thus reduced but not completely eliminated, which in turn leads to faster healing.

DISCUSSION

Laser penetration depth is of paramount importance, especially in the medicine and dentistry. But it would be wrong to base an evaluation solely on penetration depth. Penetration depth should always be looked at in connection with the respective wavelength and the to-be-treated tissue. In general, penetration depth is kept to a minimum by tuning the wavelength to the target tissue. There is only one meaningful exception where transmission is desired, and that is when treating infected hard tissue in the root canal or infected bone material. In this case germ reduction in the deeper layers is required. In all other cases absorption of the laser light in the tissue should be as high as possible. The higher the penetration depth, the less the thermal effects in deeper tissue layers can be controlled and the higher the risk for necroses.

The wide-spread and repeatedly-voiced belief that Nd:YAG lasers have the highest penetration depths in the soft tissue is only partly correct. It is correct that Nd:YAG lasers would have an extremely high penetration depth, if we were to use a regular industrial laser, with continuous wave mode of operation and non-contact laser power delivery. The Nd:YAG laser systems that have been introduced into dentistry by various manufacturers are free-running pulse Nd:YAG lasers. Their pulse durations lie between 90µs and 150µs, their laser energy is delivered through a fiber onto the target tissue or through direct contact between the fiber and the tissue. Penetration depth is thus significantly reduced. Professor Dr. Joel White from the University of California, San Francisco (UCSF) conducted a very descriptive study that supports this. A study conducted at the RWTH, Aachen, proves that a free-running pulse Nd:YAG laser has a penetration depth of approximately 0.1mm to 0.3mm, whereas a continuous wave mode Nd:YAG laser has a penetration depth of up to 6mm.

For diode lasers repetition rate and pulse duration are specific to their application areas. From a fundamental technical-physical viewpoint diode lasers deliver a continuous laser beam and are thus continuous wave lasers. If the diode laser system is capable of delivering the laser in pulses, i.e. an interrupted laser beam, it is a pulsed diode lasers. Pulsing is achieved by electronically switching the laser on and off. It must be understood that with this method the laser power in a pulse is not increased, and is in the order of several Watts. On the other hand, free-running pulse Nd:YAG laser systems can generate high peak powers where individual pulse powers can reach several thousands of Watts. This allows this type of lasers to deliver the required energy to the target tissue before the absorbed heat can dissipate from the treated area. Free-running Nd:YAG lasers are therefore for the same intended effect less damaging to the untreated surrounding tissue.

Although no comparative studies have been conducted to investigate the need for water-spray cooling in diode laser procedures, from a biophysical point of view it could be said that a water-spray would be counter-productive. Water is a good heat conductor and removes heat; a thermal effect is actually desired.

Cooling at the tissue surface level is linked to the risk of causing deeper tissue necrosis. Water-sprays should thus not be used in the diode laser procedures.

CONCLUSION

In conclusion, the table bellow summarizes the lasers of choice for specific indications in laser dentistry.

Lasers of choice per application area
ENDODONTICS - germ reduction
1. Pulsed Nd:YAG laser
2. 810 nm diode laser
3. 980 nm diode laser
Er:YAG, Er,Cr:YSGG lasers for smearlayer and tissue removal
PERIODONTICS – closed curretage
1. Pulsed Nd:YAG laser
2. 810 nm diode laser
3. 980 nm diode laser
4. Er:YAG laser with special PA-tip
PERIODONTICS – open curettage
1. Er:YAG laser
2. CO_2 laser
3. Er,Cr:YSGG laser
IMPLANTOLOGY – implant uncovering
1. Er:YAG laser with variable pulse durations or surgical tip
2. CO_2 laser
3. Diode lasers
IMPLANTOLOGY – peri-implantitis (closed)
1. 810 nm diode laser
2. 980 nm diode laser
3. Fiber-delivered Nd:YAG or Er:YAG laser with special PA-tip
IMPLANTOLOGY – peri-implantitis (open)
1. Er:YAG laser with short pulses
2. Er,Cr:YSGG
3. CO_2 laser (limited)
SOFT TISSUE SURGERY (frenectomy)
1. Er:YAG laser with long pulses
2. Er,Cr:YSGG laser
3. Er:YAG with special surgical tips and normal pulse durations
or
1. 810 nm diode laser
2. Pulsed Nd:YAG laser (limited)
3. 980 nm diode laser (limited)

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Since 1992, Prof. Dr. Norbert Gutknecht has been the head of the Aachen Research Institute for Lasers in Dentistry (AALZ) at the Clinic of Conservative Dentistry, Periodontology and Preventive Dentistry at the University Hospital of the RWTH in Aachen, Germany. He is co-founder and president of the German Society for Laser Dentistry (DGL) and Organizing Chairman of the International Society for Lasers in Dentistry - ISLD. As Editor of the Laser in Medical Science Journal and as a visiting Professor at the University of Nice and Sao Paulo, he is an established expert in Laser Dentistry. His national and international workshops on indications and treatment expectations in laser-based dental therapy are widely visited.

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