Lasers in Dentistry

In caries therapy – the most frequent dental surgery conventional mechanical drills are still superior compared to most types of lasers, particularly CW or long-pulse lasers. Only laser systems capable of providing ultrashort pulses might be an alternative to mechanical drills.

The Human Tooth

Before going into the details of laser dentistry, a brief summary of the anatomy of the human tooth as well as its physiology and pathology shall be given. In principle, the human tooth consists of mainly three distinct segments called enamel, dentin, and pulp. A schematic cross-section of a human tooth is shown in Fig. 1.

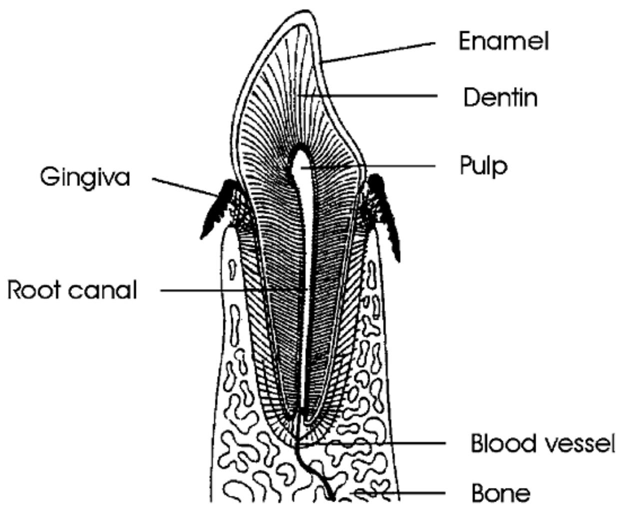

Fig. 1.Cross-section of a human tooth

The ***enamel*** is the hardest substance of the human body. It is made of approximately 95 % (by weight) hydroxyapatite, 4 % water, and 1 % organic matter. Hydroxyapatite chemical formula $Ca_{10}(PO_4)_6(OH)_2$. Its substructure consists of tiny crystallites which form so-called enamel prisms with diameters ranging from 4μm to 6μm. The crystal lattice itself is intruded by several impurities, especially Cl^- ,F^- ,Na^+,K^+, and Mg^2.

The ***dentin***, on the other hand, is much softer. Only 70 % of its volume consists of hydroxyapatite, whereas 20 % is organic matter – mainly collagen fibers – and 10 % is water. The internal structure of dentin is characterized by small tubuli which measure up to a few millimeters in length, and between 100 nm and 3μm in diameter. These tubuli are essential for the growth of the tooth.

The ***pulp***, finally, is not mineralized at all. It contains the supplying blood vessels, nerve fibers, and different types of cells, particularly odontoblasts and fibroblasts. The pulp is connected to peripheral blood vessels by a small channel called the root canal. The tooth itself is embedded into soft tissue called the gingival which keeps the tooth in place and prevents bacteria from attacking the root.

The removal of infected substance is usually accomplished with conventional mechanical drills. These drills do evoke additional pain for two reasons. First, tooth nerves are very sensitive to induced vibrations. Second, tooth nerves also detect sudden increases in temperature which are induced by friction during the drilling process. Pain relief without injection of an anaesthetic was the basic ulterior motive when looking for laser applications in caries therapy. However, it turned out that not all types of lasers fulfill this task. Although vibrations are avoided due to the contactless technique, thermal side effects are not always eliminated when using lasers. CW and long-pulse lasers, in particular, induce extremely high temperatures in the pulp. Even air cooling does not reduce this temperature to a tolerable value. Thermal damage is negligible only when using ultrashort pulses.

Laser Treatment of Hard Tooth Substance

First experiments with teeth using the laser as a surgical tool were performed by Goldman et al. (1964). They used a pulsed ruby laser at a wavelength of 694μm. This laser induced severe thermal side effects such as irreversible injury of nerve fibers and tooth cracking. A few years later, a CO_2 laser system was in vestigated (1972). However, the results did not improve very much compared with the ruby laser. These observations are due to the fact that both ruby and CO_2 lasers are typical representatives of thermally acting lasers. Thus, it was straight forward to conclude that without being able to eliminate these thermal effects, lasers would never turn into a suitable tool for the preparation of teeth.

At the end of the 1980s, the Er:YAG laser was introduced to dental applications. The wavelength of the Er:YAG laser at 2.94μm matches the resonance frequency of the vibrational oscillations of water molecules contained in the teeth. Thereby, the absorption of the Er:YAG radiation is strongly enhanced, resulting in a high efficiency. However, the sudden vaporization of water is associated with a pressure gradient. Small microexplosions are responsible for the break-up of the hydroxyapatite structure. High-magnification photographs of a human tooth after Er:YAG laser exposure were shown in Figs. 2 (a) and (b). The coincidence of thermal (e.g. vaporization) and mechanical (e.g. pressure gradient) ablation effects has led to the term "thermomechanical interaction".

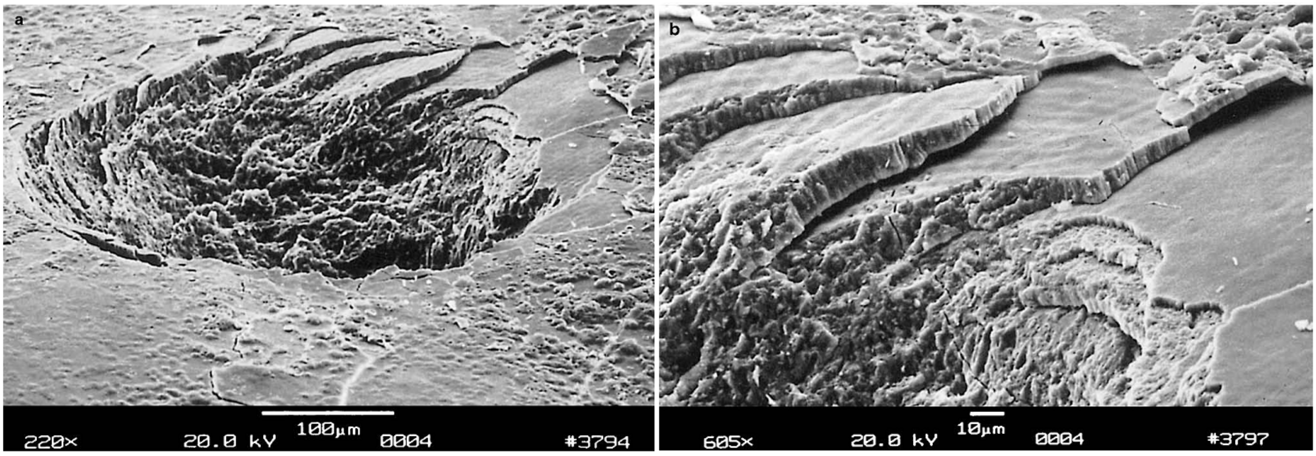

Fig. 2. (a) Human tooth vaporized with 20 pulses from an Er:YAG laser (pulse duration: 90µs, pulse energy: 100 mJ, repetition rate: 1 Hz). (b) Enlargement showing the edge of ablation.

Initially, Er:YAG lasers seemed to be very promising because of their high efficiency in ablating dental substances. Meanwhile, though, some indication has been given that microcracks can be induced by Er:YAG laser radiation. It was found by using scanning electron microscopy and dye penetration tests – that these fissures can extend up to 300 µm in depth. They could thus easily serve as an origin for the development of new decay. External cooling of the tooth might help to reduce the occurrence of cracking but further research needs to be performed prior to clinical applications.

Even worse results were found with the Ho:YAG laser. High-magnification photographs of a human tooth after laser exposure were shown in Figs. 3 a–b. Severe thermal effects including melting of tooth substance were observed. Moreover, cracks up to 3 mm in depth were measured when performing dye penetration tests.

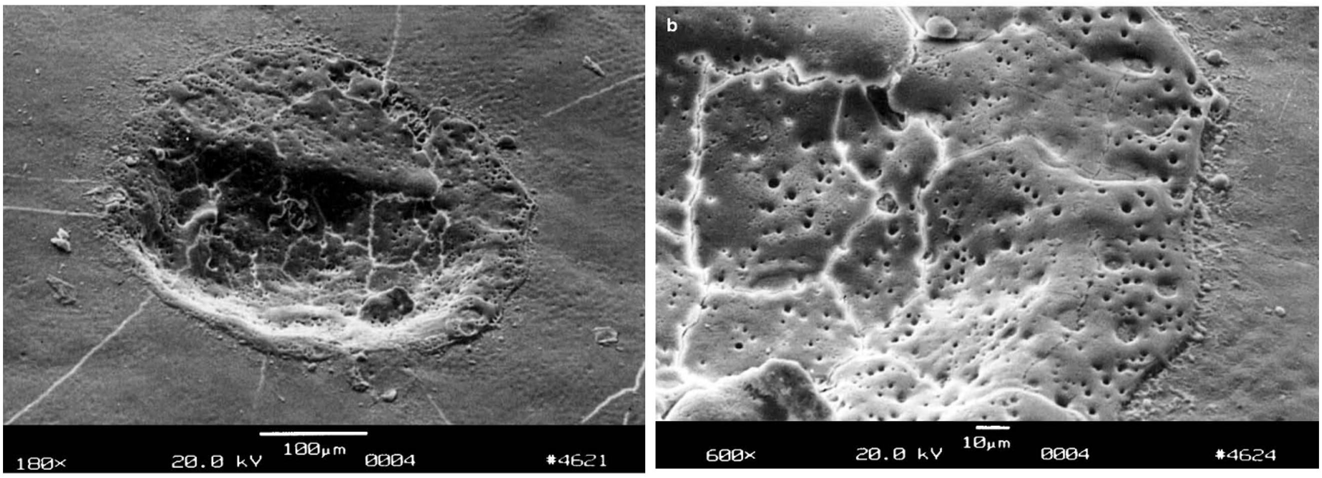

Fig. 3. (a)Human tooth melted with 100 pulses from a Ho:YAG laser (pulse duration: 3.8µs, pulse energy: 18 mJ, repetition rate: 1 Hz).(b)Enlargement showing the edge of the melted zone

Dye penetration tests are suitable experiments for the detection of laser-induced tooth fissures. After laser exposure, the tooth is stained with a dye, e.g. neofuchsine solution, for several hours. Afterwards, the tooth is sliced using a microtome, and the maximum penetration depth of the dye is determined. The results of some representative measurements are summarized in Fig. 4. Obviously, tooth fissures induced by Ho:YAG and Er:YAG lasers must be considered as a severe side effect.

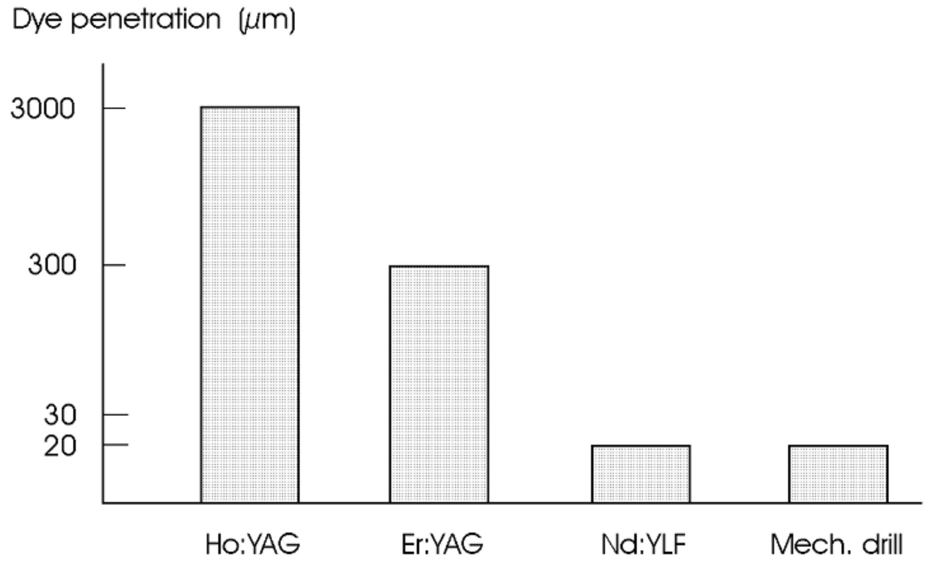

Fig. 4. Results of dye penetration tests for three different solid-state lasers and the mechanical drill. Listed are the maximum penetration depths inside the enamel of human teeth. Pulse durations: 250µs(Ho:YAG),90µs(Er:YAG),and 30 ps (Nd:YLF).

Another laser type – the ArF excimer laser – was investigated in (1989) regarding its usefulness in dentistry. Indeed, initial experiments proved that only very slight thermal effects were induced which was attributed to the shorter pulse duration of approximately 15 ns and the gentle interaction mechanism of photoablation. However, the ablation rate achieved with this laser, i.e. the ablated volume per unit time, is too low for clinical applications. This ineffectiveness and the general risks of UV radiation are the major disadvantages concerning the use of the ArF laser in dentistry.

Recently, in 1994 a novel approach to laser caries therapy has been made. When using picosecond pulses from a Nd:YLF laser system. Although, at the early stage of experiments, uncertainty predominated concerning potential shock wave effects, it has meanwhile been verified by five independent tests that mechanical impacts are negligible. These consist of scanning electron microscopy, dye penetration tests, hardness tests, histology, and polarized microscopy.

Laser Treatment of Soft Dental Tissue

Several studies have been reported on the use of a CO_2 laser in the management of malignant, premalignant, and benign lesions of the oral mucosa, e.g.. Since the oral environment is very moist, radiation from the CO_2 laser is used for such purposes because of its high absorption. When treating a soft tissue lesion inside the mouth, the surgeon has a choice of two techniques – either excision or vaporization. It is usually preferable to excise the lesion because this provides histologic evidence of its complete removal and confirmation of the preceding diagnosis. During vaporization, a risk always remains that not all altered tissue is eliminated. Hence, if a pathologic lesion is vaporized, a biopsy should be obtained from the adjacent tissue after the treatment.

The CO_2 laser is particularly useful for small mucosal lesions. Most of them can be vaporized at a power of 5–10 W in pulsed or CW mode. One major advantage is that there is no need to suture the wound, since small blood vessels are coagulated and bleeding is thus stopped. The wound edges can even be smoothed with a defocused beam. Wound healing usually occurs within a period of two weeks, and the process is complete after about 4–6 weeks. The procedure well and initially complain of little pain. However, the treated area may become uncomfortable for approximately 2–3 weeks.

Malignant lesions require a higher laser power of approximately 20–30 W to deal with the bulk of the tumor, that the recurrence of local tumors is reduced when using the CO_2 laser rather than a mechanical scalpel. The thermal effect of the radiation is made responsible for this observation. However, it is questionable whether laser treatments of malignant oral tumors are successful during a longer follow-up period, since metastases have often already spread to other parts of the body. In these cases, laser application is restricted to a palliative treatment. A specimen, for biopsy can also be excised with a CO_2 laser as one would do with a conventional scalpel. More recently, in (1988) reported on the application of a Nd:YAG laser in the treatment of oral cancer. However, in the treatment of soft dental tissues, this laser has not gained clinical relevance so far.