The Evolution of a New Area in Dentistry: A Review of the Origins and Rise of a New and Modern Technology – The Hard-laser Technique – at the University of Vienna Dental School

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Summary: The focus of this review article is on the development of laser technology in our department at the University of Vienna Dental School. Professor Sperr presented this paper upon the occasion of his emeritization.

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It was a long time ago, in the year 1965, when Goldman and his team published the first results of a trial about the effect of laser beams on hard dental tissue.[1] At that time, this technology was used in general surgery for cutting soft tissue and coagulation, with the additional advantage of a germ-free operation field.

Dentistry dreamed of contact-free preparation, which would avoid the transfer of vibrations from the preparing instrument to the prepared tooth and thus provide painless treatment, greatly increased comfort for the patients, and reduce the patients' fear of dental appointments.

At that time, four laser types were under discussion:

- Gas lasers – using atoms, ions and gas molecules ($Ar+$, CO_2) as a laser medium.
- Solid-state lasers – using rare-earth metals (Nd^{3+}, Ho^{3+}, Er^{3+}) as a laser medium.
- Dye lasers – using complex organic dyes such as Rhodamin 6G in liquid solution.
- Semiconductor lasers – working with crystal semiconductors (GaAs, PbSn, Te, Zn, Cd) – the diode lasers.

The ideas from these early investigations encouraged me and my colleagues to focus our interests on this field as well. In the first period of our evaluations, CO_2 equipment, which was especially designed for dental use, was our only option. With its wavelength of 10,600 nm, a power setting between 0.5 and 5.0 W, an irradiation length between 0.1 and 9.9 s and a continuous-wave operation mode, it wasn't really a very powerful device in comparison to the units being used nowadays (Fig 1).

That was the reason for total failure in our investigations in terms of hard-tissue preparation. The only effect we could observe was carbonization in dentinal areas and we had to remove these carbonized layers with an excavator to continue the "preparation" (Figs 2 to 4).

Of course, the preparation in enamel had to be done by rotating diamond instruments at that time.

Fig 1 Our first CO_2 laser device 1986.

Fig 2 Carbonization.

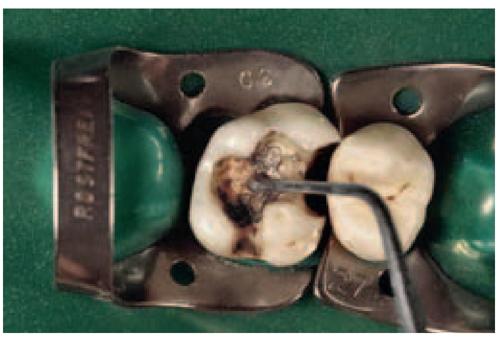

Fig 3 Excavation.

Fig 4 Final situation after the first attempts of laser preparation in dental hard tissues.

Dentin hypersensitivity

We were not dismayed by the unpromising results in hard-tissue preparations, and therefore we looked for other treatment indications. It did not take long until we discovered a very useful application. The problem of hypersensitive dental necks is very well known in dentistry; patients suffer from its persistent reoccurrence only a short time after the last conventional treatment. The reasons for the painful sensations are various: erosion, false dental hygiene, malocclusion, and iatrogenic factors seem to be the most important ones. At that time, many investigators had already tried to find an appropriate and adequate therapy mode using a Nd:YAG laser.[2-5] After a number of very promising in vitro investigations, we confidently started our in vitro evaluations.[6]

While the pure irradiation with a CO_2 laser produced a very rough pattern on the dentin surface, the application of the so-called combination therapy[7,8] – placing a layer of SnF_2 gel over the dentin before the CO_2 irradiation – produced a perfect long-lasting effect almost after two to three applications. The REM image shows a smooth surface compared to the treatment without the use of fluoride gel (Fig 5). The reason for these perfect results was the complete closure of the openings of the dentinal tubules (Fig 6).

The comparison between the test group (Fig 7) and the control group (Fig 8) shows the significant difference in the treatment success.

The most favorable aspect is that the pain-free effect lasts for a very long time; as you can see in Fig 7, patients report symptom-free status for up to 72 weeks.

These results are confirmed by the enclosure of Sn and F, as you can see clearly in the x-ray absorption spectrum after laser irradiation through a SnF_2 layer in the superficial dentin (Fig 9).

The setting of the laser device is 0.5 W with an irradiation duration of 5 s in continuous wave and defocused operation mode and a repetition rate of 6 times with an interval of 20 s between the treatment cycles. Later on, other investigators also treated dentinal hy-

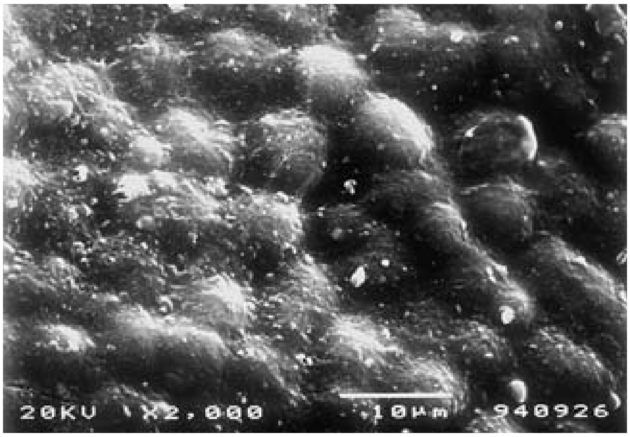

Fig 5 SnF_2 gel+irradiation.

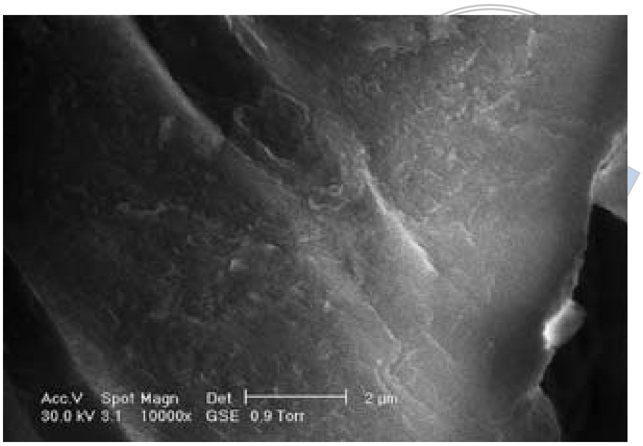

Fig 6 Complete sealing of the tubule orifice after SnF_2 gel and laser irradiation.

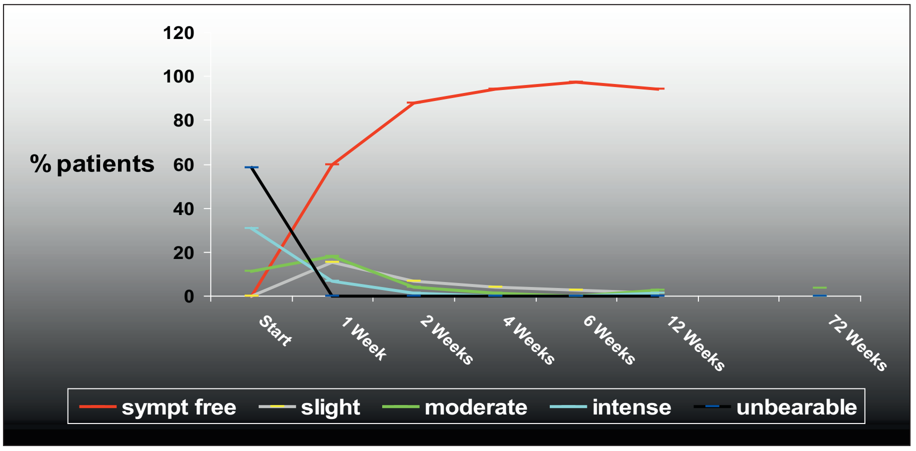

Fig 7 VAS pain scale of test group.

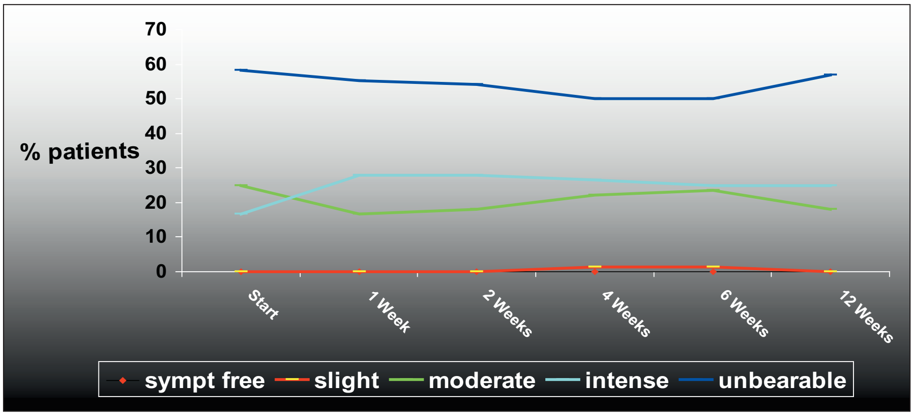

Fig 8 VAS pain scale of control group.

persensitivity with CO_2 laser support and showed that there was no thermal irritation and no thermal damage to the pulp.[9]

Direct pulp capping

Trying to keep all prepared teeth vital is sometimes not easy, especially when the carious lesion is very deep

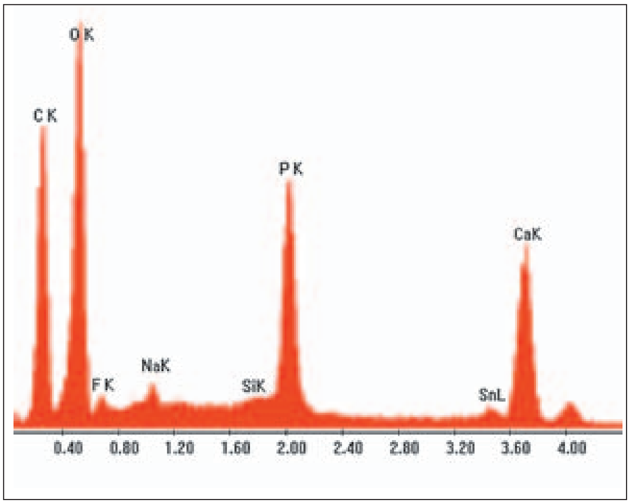

Fig 9 X-ray absorption spectrography after combination therapy.

and comes close to the pulpal region. So the first real breakthrough on our way to integrate lasers in conservative treatment was success in direct pulp capping. The main idea was that the operation field becomes sterile and CO_2 laser irradiation stops bleeding immediately. Both facts are very important for the final result of these cases. The opened pulpal cavities were covered with a calcium hydroxide layer immediately after irradiation.

As we had a second CO_2 laser device in the department at that time with much more power (1 to 20 W) and a different operation mode (pulsed and superpulsed) with an adjustability of the pulse length and frequency between 0.05 and 1.0 s, we examined 3 groups, consisting of 100 patients each. The first group was treated with the new superpulsed laser, the second with our old CO_2 laser in continuous-wave operation mode, and the third group conventionally with a covering layer of calcium hydroxide only. The vitality of the treated teeth was controlled by laser doppler flowmetry to obtain objective results on the one hand, and by conventional temperature provocation on the other hand to check the functionality of the nerve tissues.

After a period of 6 months, the conventionally treated group dropped down to a survival rate of 70%, the group treated with CO_2 laser in continuous wave operation mode reached 90%, while the group after treatment with the superpulsed CO_2 laser showed a survival rate of 96%. After a period of 18 months, the results reached a stable level. Thus, the final evaluation results were 94% for the superpulsed laser, 86% for the continuous wave laser, and 68% for the group treated in the conventional way (Fig 10).

Focusing on the diameter of the opened pulp cavity, we could see that we succeeded up to an opening diameter of 1.5 mm, which never is possible using calcium hydroxide alone.

So at that time, laser-assisted treatment of accidental pulp openings during preparation was established as standard therapy at our department.

The results were also published in national and international journals[10-12] and in many oral presentations at national and international meetings.

Endodontic treatment

The next field of interest concerning laser-supported treatment was infected root canals – a real problem in endodontics.

Because the stiff tubes of the CO_2 lasers were very uncomfortable, the diameter of 1 mm too thick, and – most importantly – the wavelength of 10,600 nm is not ideal for use in the root canal system due to the shallow penetration depth in dentin tissue, we needed other wavelengths. These were provided by the Nd:YAG and diode lasers with 1064 nm and 805 nm.

Using these lasers, we documented a significant germ-reducing effect in the first in vitro studies[13,14] and in later in vivo studies as well.[15] The flexibility of the delivery systems of these lasers with a diameter of only 300 µm were additional advantages, because we had to enlarge the root canals only up to ISO 40 to reach down to the apex with the flexible fibers, and we could also treat curved canals. In our evaluations, we found that the number of Staphylococci and Streptococci dropped under the limit of evidence at least after three treatments.[16] It was also possible to eliminate Escherichia coli and Enterococcus faecalis.[17]

The reason for the perfect results we achieved in these cases is that the penetration depth of bacteria reaches up to 1100 µm,[18] while irrigants are only effective up to a depth of 100 µm.[19] It should additionally be mentioned that due to the complexity of the root canal configuration, it is quite impossible to interact with the microorganisms in all the hidden places in the tubule system using conventional instrumentation or irrigation. The only way in all these cases is the laser-supported root canal treatment if you want to get a perfect result in the shortest time possible. As the aim of modern endodontic treatment is to avoid apical periodontitis, laser support is the best we can do at the

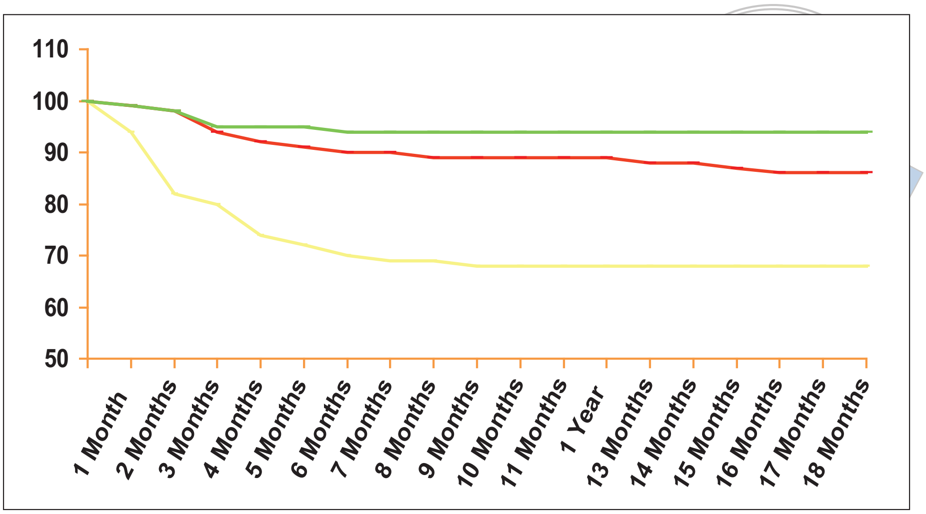

Fig 10 Survival rate of teeth; superpulsed – green, pulsed – red; conventionally treated – yellow.

moment. Of course, you can also get good results by perfect endodontic technique in cases of apical periodontitis, but it takes a long time of observation to control the slow healing process, while the laser support shortens this period significantly. The setting that proved best was 1.5 W/10 ms/50 Hz per root canal with a repetition rate of 5 cycles per session using a Nd:YAG laser.

Periodontology

There is also another very important area of dentistry which urgently needs germ reduction – all the periodontal diseases.

Using a diode laser with a setting of 1.5 to 2.0 W/50 Hz/10 ms, pathogenic organisms are killed, which leads to a reduction in inflammation and thus of the pocket depth. In comparison to a control group, we found a significant difference in pocket depths after treatment with lasers.[20]

So it is always a wonderful help in difficult cases. Even if the two very resistant germs Actinomyces actinomycetem comitans and Porphyromonas gingivalis are present, laser therapy proves to be successful because both bacteria are sensitive to irradiation by Nd:YAG and diode laser.

Of course, laser therapy does not eliminate a general problem in periodontology – sufficient cooperation of the patients. Without perfect oral hygiene and well-organized recall, you will never get a perfect result. Lack of compliance will result in a recurrence of the disease after the initial decrease or elimination of all the microorganisms.

Additionally, we should not forget the support of lasers in surgical intervention which is sometimes need ed during periodontal treatments. The good overview, the sterile operation field, and the short healing period are advantages on which we can today rely.

Conditioning of hard dental tissue

During our experiments on hard-tissue preparation, we discovered a very interesting side effect. Enamel and dentin showed a microscopic change of the surface after irradiation. Comparing the new surface pattern to that after acid etching, it looked quite similar. That was the reason for us to check whether there is an increase in adhesion after irradiation with different lasers when used with composite resins, and whether the result is comparable to the adhesion after conventional treatment.

This was the beginning of an investigation series dealing with the conditioning effect on enamel and dentin surfaces under different conditions. We compared conventional to laser-conditioned hard-tissue surfaces in enamel and dentin. The conventional acid-etching technique – with phosphoric and maleic acid – was compared to laser preparation at different power settings (low/medium/high) and wavelengths. After fixing a round composite test specimen with a standardized base (diameter 3.6 mm) on the hard-tissue samples, the shear bond strength was measured

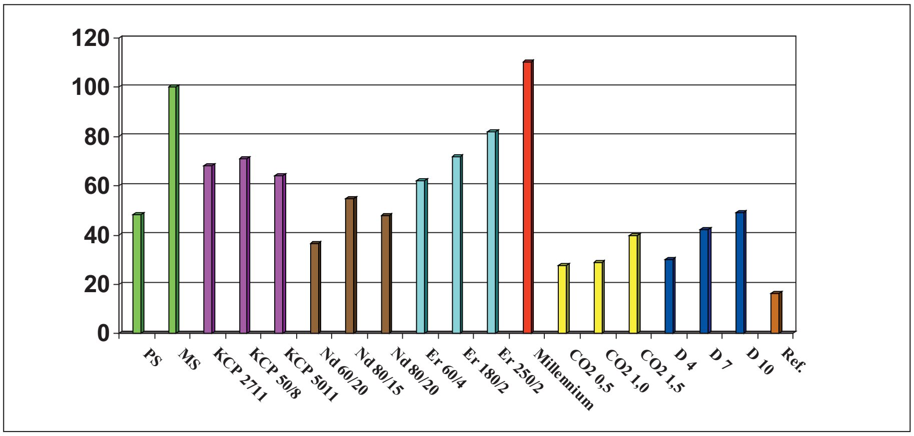

Fig 11 Shear bond strength results in enamel (in N).

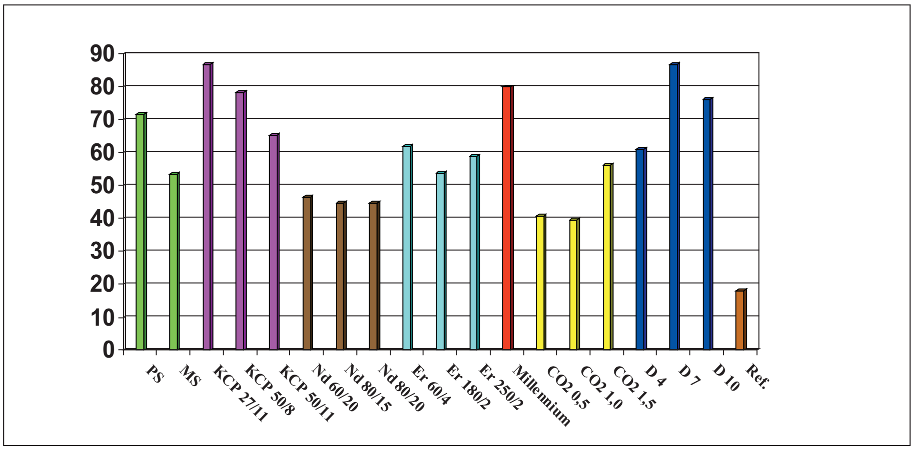

Fig 12 Results in dentin (in N).

with a testing machine with a maximum power of 200 Newtons (N), a speed of 1 mm/min, and a measurement accuracy of 0.01 N. A Kinetic Cavity Preparation system was also included, working contact-free with two sizes of aluminum oxide particles (diameter 27 µm and 50 µm) and low, medium, and high pressure of up to 11 bar. This system works similarly to sandblasting equipment. The lasers used were of the types Nd:YAG (1064 nm wavelength), CO_2 (10,600 nm wavelength), Er:YAG (2940 nm), diode laser (805 nm wavelength), and an Er,Cr:YSGG laser (2780 nm wavelength). The shear bond strength results are shown in Fig 11.

In Fig 11, you see the results of this investigation in enamel. The Er,Cr:YSGG laser (Millenium) produced the best results (over 100 N) followed by phosphoric acid and the Er:YAG laser. In general, the results above 60 N are really good and usable in practice – all the others below 60 N are poor.

As the functional loading on the surfaces of the fillings mostly have an oblique characteristic, the importance of shear bond strength is much higher than the quality of tensile strength.

So if we think about mechanisms of canine guidance, of balancing contacts in the premolar and molar region – which we chiefly find today in the occlusion patterns of elderly persons – and of course also of the chewing and swallowing mechanisms during our everyday life, we hope that in the future, filling materials with perfect adhesive properties will withstand all these stresses.

Looking at the 60 N line in Fig 12, we see that phosphoric acid, the KCP system, Er:YAG laser, Er,Cr:YSGG laser, and the diode laser reached the necessary limit, and these last results from the 805-nm wavelength irradiation were a big surprise for us, because we didn't expect them. These results were published in the years 1996[21] and 1998.[22]

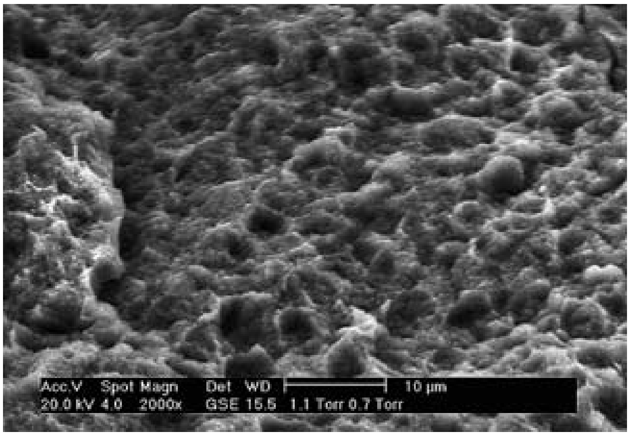

Fig 13 Cross-cut section.

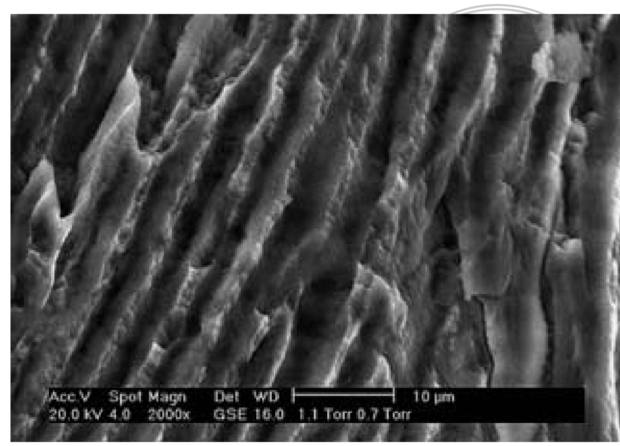

Fig 14 Longitudinally cut section.

We know now that when we prepare a cavity by laser irradiation, we will get a conditioned and sterile hard-tissue surface with no smear layer as a side effect, and do not need additional acid-etching support for the final bond connection with composite material.

Preparation

This knowledge encouraged us to focus more on preparation possibilities. The big advantage of the laser preparation of hard dental tissue is the contact-free working situation. By avoiding any vibration transfer to the teeth, significant pain reduction takes place during this uncomfortable treatment period, and only when you prepare very close to the area of the vital pulp do the patients report a little warming effect. But the increase in temperature does not exceed more than 2.5°C. As the pulp tissue can stand temperature changes up to 5.5°C without degeneration, we are on the safe side using laser preparation techniques.

Experimental in vitro studies have shown that if you want to have a fast preparation effect, you have to use special wavelengths which must have special properties.[23,24] The laser wavelength should not show transmission, but an absorption maximum in the surface tissue layer. This will cause a maximal ablation rate, because 100% of the energy is absorbed in the superficial layer of the dental tissue. That's why two laser wavelengths are currently used mainly for preparation: 2780 nm (= Er,Cr:YSGG) and 2940 nm (= Er:YAG). These two wavelengths are very suitable not only for preparation but also for fissure sealing and conditioning.

It is possible to cut enamel in any direction in reference to the prism axes, but the surface pattern changes slightly. Cross-cut surfaces (Fig 13) show a pattern like a central etch type described by Silverstone, and of course some starting ablation clefts. Longitudinally cut enamel shows the interprismatic substances and loose enamel prisms (Fig 14). These loose prisms are removed from the surface by the power of the microexplosions of the laser beams of the Er:YAG or the Er,Cr:YSGG laser. These microexplosions are supported by the presence of water. We always have to work under water spray to support this effect and to guarantee additional cooling during preparation.

Clefts of the starting ablation are chiefly found in the oblique cut view (Fig 15). Starting from very small clefts, they enlarge more and more until the moment of ablation occurs. That is why we can work in any direction of the enamel layer and do not have any problem with shaping the cavities.

By changing the laser power setting we are able to change the ablation rate – a fact we should be aware of when we are working in superficial layers in enamel, where we can work with higher power settings compared to deeper zones of dentin, where we have to be very careful working with lower power settings not to warm the pulp tissue by more than 3 to 4.4°C and to reduce the ablation rate to a minimum for very delicate preparations.

Looking at Fig 16, we see the significant difference of the ablation rate in dentin using the Er:YAG laser with different power settings from 2 to 5 W in an in vitro investigation. Of course, 5- and 6-W settings are never used in vivo to avoid the problems I have men-

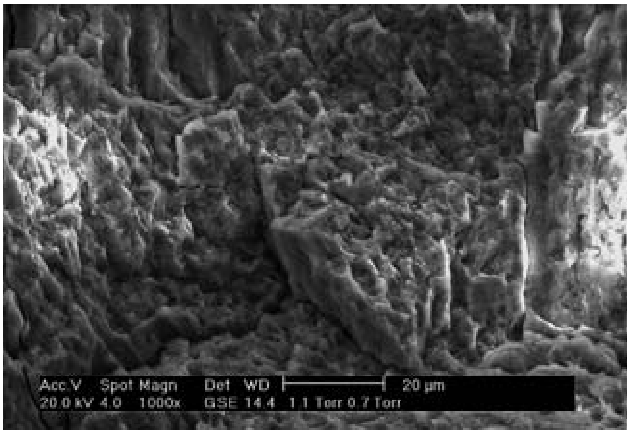

Fig 15 Obliquely cut section.

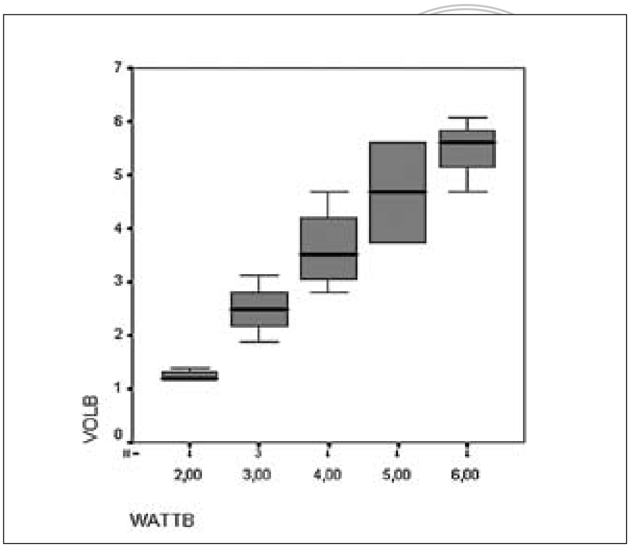

Fig 16 Ablation volume in correspondence to applied energy.

tioned above. So it is up to us to regulate the speed of the preparation, and in all cases with very deep carious lesions, we are able to reduce the ablation to values slightly over the ablation threshold for the benefit of the vital pulp and the patient's tooth.

Using composite resin filling materials, laser preparation is really perfect and well practicable: the cavities are clean – there is no smear layer and there are no microorganisms – and patient acceptance is high.

SUMMARY

There is almost no field in dentistry where we do not derive a supporting benefit of the innovative treatment from different laser types and wavelengths. Nearly painlessly, steriley, and noiselessly we can treat our patients, and the laser support guarantees us a better and faster result.

From the early years of laser technology use for dental treatments with only a few indications, the range of indications has widened substantially to currently include nearly all fields of dentistry.

Today, the positive effect of laser supported treatment in almost every area of dentistry very impressively shows that the different lasers with their special qualities and wavelengths are irreplaceable.

The therapy of hypersensitive dental cervices, the conditioning effect in combination with composite material not only for filling cavities but also for sealing dental fissures, the preparation of hard dental tissue in a nearly painless and silent way, and of course the results in the fields of endodontology, periodontology, and last but not least oral surgery, tell us that there is no way without this technology.

New laser generations with new properties especially designed for our needs – such as the ultrashort pulsed devices – will help to solidify the position of laser treatment in dentistry in the future and bring other, additional indications than at present.

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