Laser-assisted Apex Sealing: Results of a Pilot Study

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Purpose: In addition to the eradication of microorganisms in the root canal system, the sealing of the apex is one of the major aims of endodontic treatment. Many studies have illustrated the usefulness of lasers with regard to their bactericidal potential, and the present study was performed to evaluate the sealing ability of different laser systems.

Materials and Methods: Eighteen extracted single-rooted teeth were instrumented to a width of ISO 70. Subsequently, dentin powder with a grain size between 6 and 42 µm was condensed into the apical area of the root canal. Two of these samples were left untreated and served as controls. The remaining 16 teeth were subdivided into 4 groups and underwent laser irradiation using one of 4 different wavelengths (Nd:YAG, diode, Er:YAG, Er,Cr:YSGG) at 2 different settings. After the laser irradiation, the teeth were stained with basic fuchsin solution, sectioned longitudinally with a band saw, and examined under light and scanning electron microscopy.

Results: Using light microscopy, the sealing of the apex appeared to be complete in all samples, whereas scanning electron microscopy revealed gaps between the apical plug and the root canal wall in the majority of the samples.

Conclusion: The present study opens interesting aspects in the fields of laser-assisted endodontics. Further studies with a larger number of samples have to be conducted to acquire additional information.

Key words: endodontics, root canal filling, Nd:YAG laser, diode laser, Er:YAG laser, Er,Cr:YSGG laser, scanning electron microscopy, color penetration, apical plug, fusing.

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Endodontic treatment has continuously increased in importance in modern dentistry during the last decades. New techniques in instrumentation and filling allow the conservation of teeth which are severely endodontically damaged.

One of the fundamental aims of endodontic therapy is the disinfection of the root canal and its three-dimensional tubular network. Bacteria which penetrate into the deeper layers of root dentin propagate a periapical inflammation with subsequent destruction of the adjacent connective tissues. The eradication of persisting bacteria in distant areas of the tubular system is a major challenge in today's treatment regimens and is crucial for the long-term preservation of the endodontically treated tooth. A very useful tool for the disinfection of the root canal and the surrounding dentin is represented by different laser systems.

The most widely used lasers in endodontics, the Nd:YAG and the diode lasers, emit at 1064 nm and 810 nm, respectively. Due to the wavelength in the near infrared range, flexible conductors can be used for the application in narrow and bent root canals. These lasers produce a bactericidal effect not only on root canal surfaces but also in the deeper layers of dentin. This has been proven in several studies.[1-5]

The Er:YAG laser, emitting at a wavelength of 2940 nm, is mainly used for hard tissue ablation, since its wavelength correlates closely with the absorption maximum of hydroxyapatite. When irradiated, water contained in the dental hard tissue evaporates instantaneously and thereby ablates the surrounding tissue with only minimal thermal side effects. This has been demonstrated in various studies by Hibst and Keller.[6-8]

Another wavelength established for the preparation of dental hard tissues is the Er,Cr:YSGG laser. Yamazaki et al[9] and Kimura et al[10] describe the morphological changes encountered in irradiated root canal walls.

Studies by Schoop et al[11,12] have shown a high bactericidal effect of the Er:YAG laser (wavelength 2940 nm) in endodontic procedures. A comprehensive study directly comparing the bactericidal effects of the Nd:YAG, diode, Er:YAG, and Er,Cr:YSGG lasers was conducted by Schoop et al.[13] The study ascribed a high bactericidal potential to all four wavelengths.

Another important aim of endodontic treatment is the creation of a tight seal of the apex and the root canal, impermeable for liquids and bacteria. A great number of different sealers and cements is applied in everyday endodontics, either exclusively or in combination with root canal points made from various materials.[14]

The use of lasers to achieve tight apical sealing appears to be obvious. Several authors have addressed the topic of apical leakage after conventional sealing in laser treated root canals[15-18] or the use of lasers as an aid for the application of gutta-percha fillings,[19,20] whereas only a few authors assessed the possibility of creating an apical plug by the laser itself.[21,22]

The present pilot study was carried out to assess the ability of four different laser systems (Nd:YAG, diode, Er:YAG, Er,Cr:YSGG) to achieve apical sealing with dentin plugs in vitro.

MATERIALS AND METHODS

Eighteen single-rooted human teeth were stored in physiological saline solution at 4°C immediately after extraction and further processed within 3 days. The crowns were cut off and the teeth subsequently endodontically prepared to a width of ISO 70 using the step-back technique. The remaining dentin was pulverized in a porcelain mortar to a grain size between 6 µm and 42 µm, determined by light microscopy at 400X magnification. The dentin powder was subsequently condensed into the apical region of the prepared teeth using a periodontal probe and a plugger.

Sixteen teeth were subdivided into 4 groups (A to D) of 4 teeth each and submitted to laser irradiation. For each group, a different wavelength was chosen and applied at two different power settings. The remaining 2 teeth were left untreated for control purposes.

The Nd:YAG laser used was the Pulse Master 1000 (American Medical Technologies, Corpus Christi, TX, USA) emitting at a wavelength of 1064 nm. The variable laser parameters are pulse energy (30 to 320 mJ) and pulse rate (10 to 200 Hz), resulting in a power output of 0.2 to 5W. The pulse duration is 100 µs.

The Key II (KaVo, Biberach, Germany), an Er:YAG laser, emits at a wavelength of 2940 nm, with a frequency ranging from 2 to 15 Hz, a pulse energy of 50 to 400 mJ and a pulse duration of 200 µs. This corresponds to a maximum output power of 3.75 W.

An LD 15 (Dentek, Graz, Austria) served as the diode laser. Emitting at a wavelength of 810 nm, the laser can be operated in pulsed or cw mode and a repetition rate ranging from 1.5 to 200 Hz, resulting in an output power of 0.5 - 15W. Pulse duration can be varied between 2 and 32 ms.

Finally, an Er,Cr:YSGG laser (Millennium Waterlase, BIOLASE, San Clemente, CA, USA) emitting at a wavelength of 2780 nm, was used. In this device, pulse energy can be varied between 25 and 300 mJ at a fixed repetition rate of 20 Hz. This results in an output power of 0.5 to 6W.

Each laser was equipped with a proprietary flexible waveguide and a 400-µm-diameter fiber tip, and was operated without any water spray or air cooling. The lasers were adjusted for an effective average output power of 1 W and 1.5 W, measured directly on the fiber tip using a wattmeter (Field Master, Coherent, Santa Clara, CA, USA) before each irradiation cycle. This procedure ensured stable and standardized irradiation schemes for each sample. The repetition rate was 15 Hz in the Nd:YAG, diode, and Er:YAG lasers, while the Er,Cr:YSGG device was operated at its fixed repetition rate of 20 Hz. Each specimen was irradiated for 5 times 5 s with breaks of 20 s in between, thus imitating the standardized in vivo procedure.

Table 1 illustrates the assignment of the samples to the assessment groups and the corresponding laser settings.

Following laser irradiation, the teeth were immersed in a basic fuchsin solution for 1 h at 20°C and subsequently fixed in ethanol at increasing concentrations of 70%, 96%, and 100%. The samples were then longitudinally cut to expose the root canals and the apical plug using a diamond-coated band saw (Trennschleif System, Exakt, Norderstedt, Germany) under continuous water irrigation.

Light Microscopy

The first assessment of the samples was done with a light microscope (Olympus, S761; Olympus, Tokyo, Japan) at 10X and 40X magnification. The color penetration into the apical root canal wall was checked as well as the staining of the apical plugs. To score the color penetration, a three-step scale was applied: a score of "++" meant a strong, continuous color penetration, "+" only slight dye penetration, and "0" stood for samples without any coloring of the apical plug or the root canal wall. Areas of the apical plug which were penetrated by the dye solution corresponded to marginal gaps and lack of tightness, while unstained areas represented a tight seal and molten dentin, since they appear in white color under the light microscope.

Scanning Electron Microscopy (SEM)

Six teeth were chosen for SEM. The selection criterion was a tight apex sealing according to light microscopy. The samples were assessed using a so-called environmental scanning electron microscope (Philips ESEM XL 30, Philips, Eindhoven, The Netherlands) working with slight subpressure and without sputtering of the samples, thus making it possible to assess samples in a native state with a minimum of artefacts. The teeth were examined at 25X, 40X, and 200X magnification. Particular attention was paid to the interface area between the apical plugs and the root canal walls, since the presence of marginal gaps had to be detected as well as possible bridge formations between the plugs and the original dentin.

RESULTS

Light Microscopy

The teeth in group A, which were treated with the Nd:YAG laser at 1 W, show a slight dye penetration ("+") in the upper third of the dentin plug and the root canal dentin; in contrast, in those teeth which were irradiated at the higher output power, almost no staining

Table 1 Assignment of samples

Group	Sample	Laser	Settings
A	1+2	Nd:YAG	1 W
	3+4		1.5 W
B	1+2	Er:YAG	1 W
	3+4		1.5 W
C	1+2	diode	1 W
	3+4		1.5 W
D	1+2	Er,Cr:YSGG	1 W
	3+4		1.5 W
Control	1+2	–	–

Fig 1 Sample A1, Nd:YAG, 1 W.

Fig 2 Sample A4, Nd:YAG, 1.5 W.

Fig 3 Sample B1, Er:YAG, 1 W.

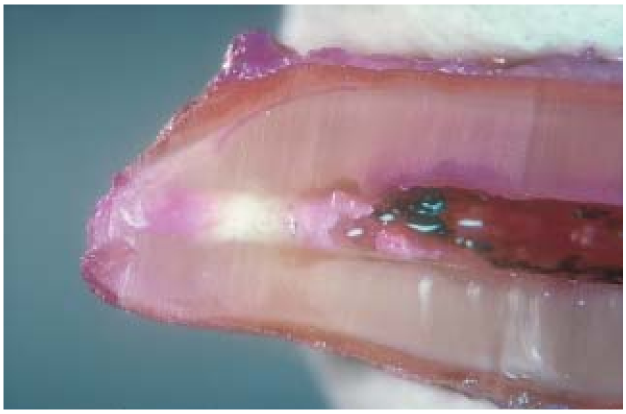

Fig 4 Sample B4, Er:YAG, 1.5 W.

Fig 5 Sample C4, diode, 1.5 W.

Fig 6 Sample D4, Er,Cr:YSGG, 1.5 W.

of the plug or the dentinal wall is discernible (score "0"). Figures 1 and 2 illustrate these results.

When the Er:YAG laser (group B) was applied at the lower setting, the dye solution penetrated into the root canal wall to a high extent ("++"). Increasing the output power to 1.5 W resulted in a reduction of dye penetration ("+"). The dentinal plugs remained mostly unstained, even though the coronal portions of the plugs were partly ablated, as can be seen in Figs 3 and 4. In addition, the higher setting of 1.5 W tended to produce carbonizations.

The diode laser in group C produced effects similar to those achieved by the Nd:YAG device. Applied at the lower setting, partial dye penetration into the plugs and the root canal wall ("+" or "++") can be seen. At the higher setting, the dentinal staining was reduced ("+" or "0"), although the results are slightly inferior to those achieved with the Nd:YAG laser, as depicted in Fig 5.

All the samples irradiated with the Er,Cr:YSGG laser (group D) show a high obstruction of dye penetration into the apical plugs as well as into the canal walls (score "0") at both power settings. Simultaneously, a rather high degree of carbonization is produced. Figure 6 illustrates the effects of the Er,Cr:YSGG laser irradiation.

A mechanically stable formation of the apical plug was achieved in all the laser irradiated samples; the plugs of the 2 control teeth were removed during the cutting procedure. The control samples showed complete dye penetration into the root canal dentin.

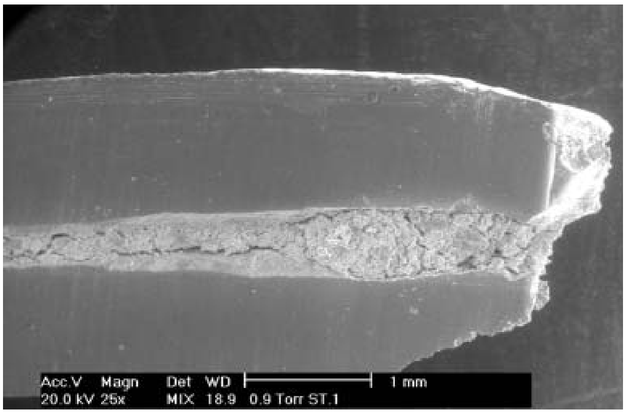

Fig 7 Sample A4, Nd:YAG, 1.5 W, 25X.

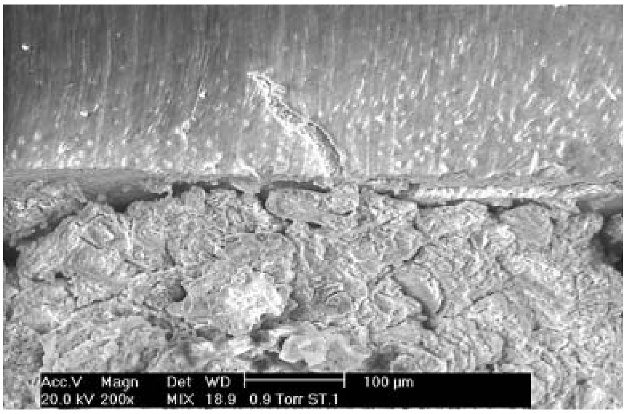

Fig 8 Sample A4, Nd:YAG, 1.5 W, detail, 200X.

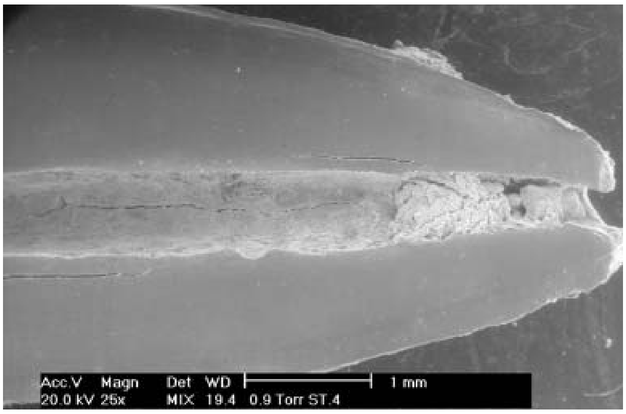

Fig 9 Sample B4, Er:YAG, 1.5 W, 25X.

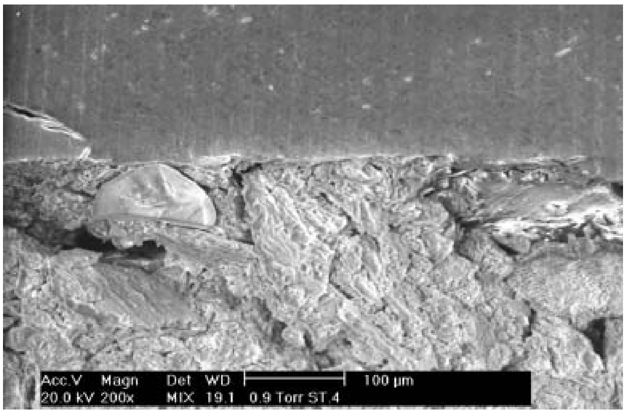

Fig 10 Sample B4, Er:YAG, 1.5 W, detail, 200X.

Scanning Electron Microscopy

Sample A4 from the Nd:YAG laser group shows a dentinal plug quite closely adhering to the root canal wall (Fig 7). The higher magnification (Fig 8) reveals marginal gaps, first of all in the apical region. Sample A1, which was irradiated at the lower settings, shows those marginal gaps even more clearly.

When the Er:YAG laser was used at the setting of 1.5 W (sample B4), areas without any marginal gaps at least over a distance of 0.5 mm can be discerned (Fig 9). Details of the interface between the dentinal plug and the root canal wall are depicted in Fig 10.

The assessment of the samples irradiated with the diode laser (sample C4) reveals rather large gaps between the apical plug and the root canal wall (Figs 11 and 12), although the dye penetration test produced results similar to those achieved by Nd:YAG laser irradiation.

The Er,Cr:YSGG laser irradiation (Sample D4) resulted in an intense blockage of color penetration. These results are reflected by the outcome of the SEM assessment. Marginal gaps are still present, but a dense interface between the plug and the root canal wall was achieved (Fig 13). At the higher magnification, these interface areas are clearly discernible (Fig 14).

DISCUSSION

The success of an endodontic treatment can be derived to a great extent from the creation of a fluid- and bacteria-tight seal of the root canal and the apical area. Since different laser systems have been established as

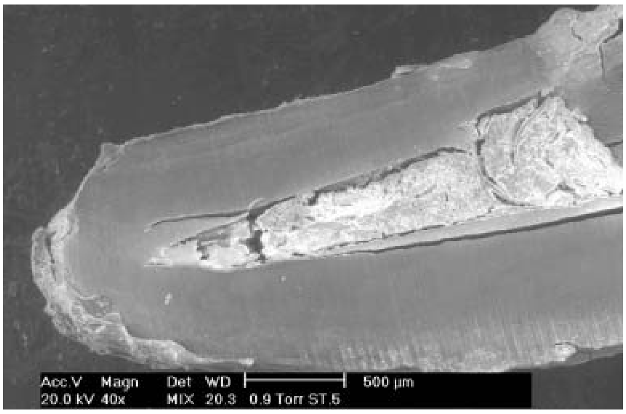

Fig 11 Sample C4, diode, 1.5 W, 25X.

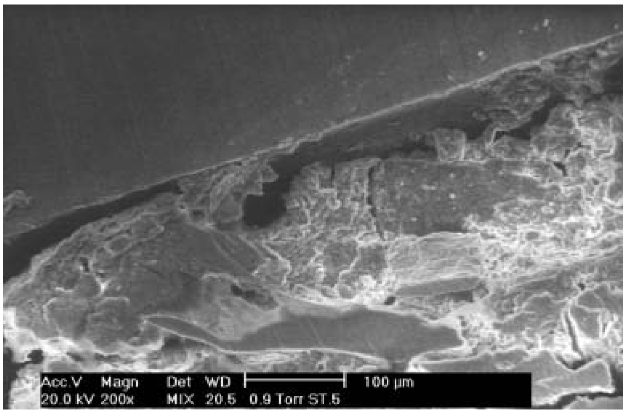

Fig 12 Sample C4, diode, 1.5 W, detail, 25X.

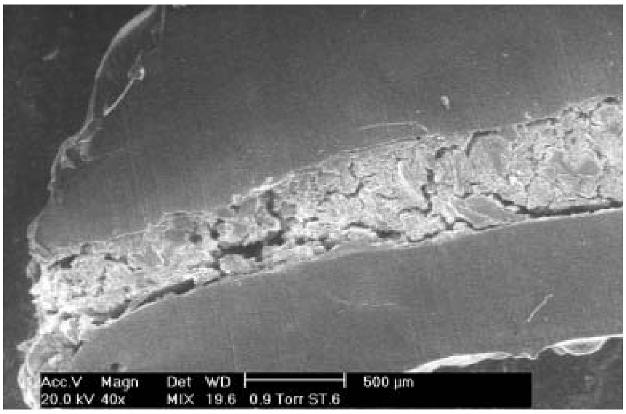

Fig 13 Sample D4, Er,Cr:YSGG, 1.5 W, 25X.

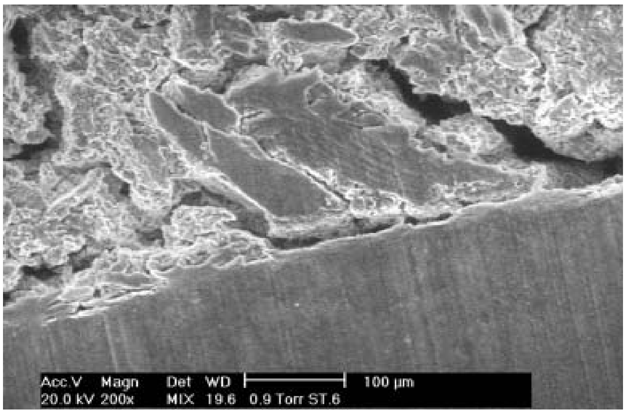

Fig 14 Sample D4, Er,Cr:YSGG, 1.5 W, detail, 200X.

effective tools for root canal preparation and disinfection, the application of the laser as an aid to apex sealing is obvious. Until now, only a few studies have addressed the topic of laser-induced root apex sealing. Neiburger[22] used a CO_2 laser to achieve this end.

The CO_2 laser as an adjunct to conventional apicoectomy was used by Moritz et al.[23] The authors succeeded in sealing the dentinal tubules, but did not strive for the laser-assisted obturation of the root canal itself.

Attempts to fuse hydroxyapatite to seal the root apex were made by Mor et al.[24] The authors utilized a XeCl Excimer laser and were only partly successful, because leakage was still observed under certain conditions.

A wavelength well established in endodontics was applied by Gekelman et al.[21] The authors compared conventionally obturated root canals with canals that had been Nd:YAG-laser irradiated prior to obturation and finally with canals in which dentinal plugs had been applied and laser irradiated. The authors checked for dye leakage and obtained the best results in the laser-irradiated and afterwards conventionally obturated group. The highest leakage rate was observed in the group with the dentinal plugs.

The present study evaluated the ability of four different laser systems to seal the apical portion of the root canal and to fuse a dentinal plug in the apical foramen. Through the irradiation procedure, mechanically stable plug formation was achieved, but leak tightness was observed in selected samples only. When the Nd:YAG laser was used at a setting of 1.5 W, which corresponds to the established standard setting for the endodontic procedure, leak tightness was achieved to a high extent. The ability of this wavelength to seal dentinal tubules has already been described in previous studies.[21,25] The same holds true for the diode laser,[26] which yielded only slightly inferior results in the present study. If "preparation wavelengths" like the Er:YAG or the Er,Cr:YSGG laser are applied, ablative effects have to be taken into account. In the present study, the Er:YAG laser produced only limited sealing effects at the higher setting. Using only 1 W, no blockage of the dye penetration into the root canal dentin was observed, since the wavelength is known to expose the orifices of the dentinal tubules.[10] In those samples irradiated with an output power of 1.5 W, carbonization effects were observed. Although it is possible that recrystallized dentin may obstruct dentinal tubules and the apical plug does seem to be fused to a certain extent, the high temperature rise may be cause for concern. The results achieved by Er,Cr:YSGG laser irradiation show this effect to an even higher extent: The dye penetration is blocked even at the lower setting, but strong carbonization effects are discernible.

Scanning electron microscopy revealed the formation of marginal gaps in all samples. The best results were achieved with the Er,Cr:YSGG laser, but a bridge formation between the plug and the root canal wall was limited to certain portions of the interface.

CONCLUSION

It can be concluded that Nd:YAG and diode laser irradiation leads to a sealing of the dentinal tubules. To a certain extent, this also holds true for the Er:YAG and the Er,Cr:YSGG laser, but only at relatively high power settings which might produce thermal side effects in vivo. The sealing effect can be utilized for the conventional obturation technique and improves the outcome with respect to leak tightness of the applied root canal filling.

The possibility of fusing an apical plug opens up new prospects in endodontics, even though the results achieved in the present study are still not reliable enough to recommend the method for clinical practice. An approach for an improvement of the method could be the application of dentin powder with a more homogenous grain size or the utilization of other materials, such as synthetic hydroxyapatite. Adding absorbers as a further component of the plug appears to be another promising approach. In any case, further investigations are necessary to establish this innovative method in modern endodontics.

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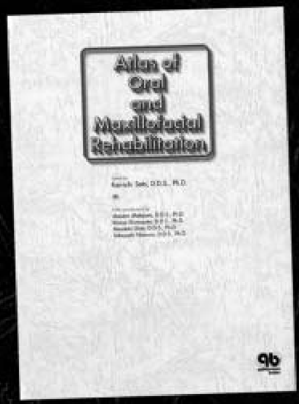
Atlas of Oral and Maxillofacial Rehabilitation



Edited by
Kan-ichi Seto

Recent advances in reconstructive surgery have greatly expanded the cure rate for malignancies of the oral cavity. This atlas presents the prosthetic rehabilitation of maxillofacial defects arising from congenital malformation, injury, inflammation, and cancer. It provides a comprehensive overview of the patterns and classifications of defects found in each region along with step-by-step procedures for fabricating the forms or appliances for treating them.

Contents

Section I: Foundations of Maxillofacial Prosthetics
- Classification
- Surgical Simulation
- Conversation, Mastication, and Deglutition

Section II: Maxillary Defects
- Defect Patterns and Classifications
- Structures and Names of Parts of Prostheses
- Measures for Treatment of Disturbance of Mouth Opening
- Impression Taking
- Forms of Prostheses and Features of Obturators
- Retention of Prostheses
- Placement of Implants to Insertion of Upper Structures
- Rapid Fabrication of Maxillodental Prosthesis
- Changes of Maxillary Defects

Section III: Defects of the Palate and Oropharyngeus
- Soft Palate Defect Prostheses
- Appliances for Cleft Lip and Palate

Section IV: Mandibular Defects
- Classifications of Defects and Treatment Planning
- Fabrication Method
- Retainer of Prostheses
- From Placement of Implants to Fabrication of Prostheses
- Alveolar Reconstruction

Section V: Facial Defects
- Patterns and Classification
- Fabrication Methods
- Retention Methods
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