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“Greetings for the day!”
Unsolicited e-mails from
questionable journals

Are zirconias of today
different?

Minimally invasive esthetic
and functional rehabilitation
after systematic periodontal
therapy: a case report

Biofilms on polymeric
materials for the fabrication
of removable dentures



This journal is regularly listed
in CCMED / LIVIVO and in ICMJE.

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“Greetings for the day!” Unsolicited e-mails from questionable journals

For some years now, people working in science have been confronted with a new phenomenon: The annoyance caused by (exclusively English-language) e-mails in which the recipients are asked – usually after a friendly greeting (Tab. 1) – to publish an article in a journal mentioned in the mail (Tab. 2). The titles of these journals are largely unknown in the dental/medical world. Sometimes they resemble those of renowned specialist journals.

In order to demonstrate the extent to which this practice has taken on, the e-mails of this kind received by the first author at his address <jens.tuerp@unibas.ch> between 1 and 31 January 2020 were stored and analyzed.

Results

Eighty-seven mails were received, i.e. almost 3 per day. They referred to 60 different titles of journals in which one may publish. Without exception, these were online journals. Thirty-seven journals are devoted to medicine, two cover the humanities and social sciences, one specializes in crustaceans, and one is multidisciplinary (Tab. 3).

Only 19 of the 60 journals were devoted to dentistry (Tab. 4). None of these are listed in PubMed or the Directory of Open Access Journals. It can be assumed that these 19 journals, like their publishers (Tab. 4), are unknown in the dental profession.

The 87 mails include 7 general enquiries from 5 publishers, each of

which provides a large range of journals. Four of these publishers are based in India (Green Publication; IP Innovative Publication; IJRDO; NN Publication), one in England (Cambridge Scholars).

While most requests were only sent once, 10 journal titles and one publisher were characterized by repeated mailings (Tab. 5). The journals that requested the most and third most frequently had no reference to dentistry at all (sociology; crustaceans).

The primary aim of most senders was apparently to make the journal or publisher known to the recipient and to promote occasional consideration when submitting an article. In other, sometimes follow-up e-mails the desire

Formulation
“Greetings!!”
“Greetings for the day!!!”
“Hope you are doing well.”
“I hope you are doing great.”
“Warm wishes to you!”

Table 1 Typical formulations at the beginning of the mails.

Request
“We are inviting you to submit your research work it can be „Full Length or Short Length“ in our journal [...]”
“The [journal] is currently accepting the manuscript for its peer review, open access publication.”
“We would like to encourage your gracious presence and your research group(s) to submit papers theme [xxx] at our esteemed Journals ...”
“We strongly encourage to venture in our [journal] given your great stature and knowledge in this arena.”
“We have gone through your huge profile online and it is very fascinating and inspiring.”
“With reference to your previous publications, we request you to contribute an article to our [journal].”
“It is our enormous pleasure to invite you to submit or recommend manuscript/papers of your research/review/study to [journal], a peer-reviewed and open access international academic journal publishes high quality and original research papers, reviews, and case studies related to all areas in Dentistry.”
“We gladly invite you to submit your work towards [journal].”

Table 2 Typical formulations (partly in incorrect English). Examples of e-mails received between 1 and 3 January 2020

to submit a manuscript as quickly as possible was at the forefront (Tab. 6).

Evaluation

The fact that only about 30 % of the journals had a dental background shows that the sending of these mails was undirected. Obviously, the editors and the publishers of these journals approve of the fact that authors from other fields also submit manuscripts to their journals (which are then published in almost all cases). This suggests that the quality of the content of such journals is as questionable as the strategy of the publishers behind them.

Since the mentioned journals, which are designed for a dental audience, are not listed in important electronic search engines, such as PubMed or Livivo, they remain unknown to the dental readership. It can therefore be assumed that the articles published in them are not taken note of by the scientific community, i.e. are neither read nor cited.

Overriding problem

It can further be assumed that the vast majority of these dubious journals and their publishers are so-called predatory journals and predatory publishers, respectively. They contribute to the current publication and communication crisis in research and science.

The systematic violations of the usual publication rules, as described in this article, have now reached such proportions that the scientific community can be expected to suffer considerable damage. Publications are a central element of the scientific community. They are indispensable for the presentation of research results and form the basis for scientific discourse. The undermining of quality standards by dubious publishing practices on the part of purely commercially oriented predatory publishers therefore has direct consequences: Important research results are published in unknown journals and consequently go unnoticed, discussions on content do not even take place or can be steered in the wrong direction, misinformation spreads, scientific careers are damaged – or (in exceptional cases, and then only for a short period of time) unjustifiably promoted. How

Titles of non-dental journals
Annals of Case Reports
Annals of Sports Medicine and Research
Anxiety and Depression Journal
Archives of Medical and Clinical Psychology
Canadian Journal of Biomedical Research and Technology
Clinical and Experimental Investigations
Clinics in Medical Sciences
Current Advances in Orthopaedics and Physical Therapy
Gerontology & Geriatric Research
Global Journal of Physiotherapy and Rehabilitation
International Journal of Humanities, Social Sciences and Education
International Journal of Reproductive Medicine and Sexual Health
International Research Journal of Medicine and Medical Sciences
Japan Journal of Research
Journal of Alzheimer's Parkinsonism & Dementia
Journal of Case Reports and Studies
Journal of Clinical and Medical Images
Journal of Modern Human Pathology
Journal of Neurological Disorders & Stroke
Journal of Neurology & Translational Neuroscience
Journal of Pharmacology and Clinical Toxicology
Journal of Radiology and Imaging
Journal of Radiology and Radiation Therapy
Journal of Surgery
JSM Sexual Medicine
Korea College of Rheumatology
Medical Science Monitor
Nauplius
Neurology and Neurobiology
Neurology and Neuroscience
Nursing & Healthcare Journal

Table 3 The 41 journals not related to dentistry

Otorhinolaryngology and Hypersensitivity Treatment
RA Journal Of Applied Research
Scholarly Journal of Otolaryngology
SL Clinical Medicine: Research Journal
SM Gerontology and Geriatric Research
SM Journal of Orthopedics
Sociology Insights
Sports Medicine
Surgery & Case Studies: Open Access Journal
United Journal of Medicine and Health Care

Table 3 Continuation The 41 journals not related to dentistry

Titles of dental journals	Publisher
American Journal of Dentistry and Oral Care	Onomy Science, India
Annals of Dental Science	MedRead, USA
Dental Oral Biology and Craniofacial Research	Science Repository, USA/Estonia
ES Journal of Dental Sciences	eScientific International Open Library, Australia
European Journal of Dental and Oral Health	European Open Access Publishing, Belgium
Global Journal of Oral Science	Green Publishers, Pakistan
International Journal of Dentistry and Oral Health	BioCore, USA
Interventions in Pediatric Dentistry Open Access Journal	Lupine Publishers, USA
Journal of Dental and Maxillofacial Research	Research Open, Ireland
Journal of Dentistry Open Access	Science Repository, USA/Estonia
Journal of Oral Health and Dental Science	Scholarena, USA
JSM Dentistry	JSciMed Central, India
Modern Research in Dentistry	Crimson Publishers, USA
Online Journal of Dentistry & Oral Health	Iris Publishers, USA
Oral Health & Dental Science	Scivision Publishers, USA
SL Dentistry, Oral Disorders and Therapy	Scientific Literature, USA
Stechnolock Journal of Dentistry	Stechnolock, India
SVOA Dentistry	ScienceVolks, England
The Dentist	Medtext Publications, USA

Table 4 The 19 journals related to dentistry, and their publishers

harmful these negative structures actually are is difficult to quantify. However, the financial advantages of the providers involved can be estimated.

A new or unknown publication will be checked for its seriousness. An essential criterion for the selection decision is whether the publication organ has established its own guidelines for good scientific practice."

German Research Foundation 2019 [1] p. 21

A "glimpse into the box" was provided by the judgment of the US Federal Trade Commission (FTC) responsible for consumer protection against OMICS Group Inc., iMedPub LLC, Conference Series LLC. This Indian company operates hundreds of dubious journals and also organizes a large number of international conferences. These activities are now considered to be an essential part of junk science (often referred to as "fake science"), characterized by worthless publications or conferences [6]. The injunction enforced in March 2019 by the U.S. District Court of Nevada against Omics to immediately stop the fraudulent business practices in the U.S. was accompanied by a fine of \$50.1 million.

The practice of predatory publishers must be seen as a frontal attack on the quality of research and science and, by extension, on the academic system, including industrial research, and must be taken seriously accordingly. The massive violations of the quality rules for publishing were made possible by the structural shifts in publishing operations towards so-called Open Access journals and the associated payment models.

In the traditional journal world, manuscripts containing the results of research projects were submitted by authors to academic journals, qualitatively reviewed there (with the help of external, often university-based reviewers) and printed upon successful completion of the peer review process. The corresponding journals were

Journal title	Number of mails
Sociology Insights	6
JSM Dentistry	5
Nauplius	4
ES Journal of Dental Sciences	3
NN Publication [Verlag]	3
Annals of Dental Science	2
International Journal of Dentistry and Oral Health	2
Journal of Dental and Maxillofacial Research	2
Journal of Neurology & Translational Neuroscience	2
Journal of Radiology and Imaging	2
Stechnochlock Journal of Dentistry	2

Table 5 Sources of repeated requests (January 2020)

then accessible via subscriptions or libraries.

The Open Access movement gave rise to journals that were free of charge and freely accessible to every user. To achieve this, funding was shifted from readers to authors, thus completely turning the classical model on its head. Some of the best-known representatives in medicine are *PLOS Medicine* and *BMC Medicine*, in dentistry *BMC Oral Health* and *Head & Face Medicine*. They characterize themselves as open access/open peer review medical/dental journals. They originally took over the quality-preserving processes of the classic journals (e.g. qualitative peer review of incoming manuscripts) – except for the financing, and this is exactly where the problem and the gateway for the undesirable development by the predatory journals lies.

Whereas in the traditional model a high rejection rate of submissions (over 90 % in the case of journals such as *The Lancet*) was considered a sign of quality and thus also served as a quantity limit, this mechanism is missing in open access where the financial income of publishers depends exclusively on the number of released articles. It is therefore reasonable to assume that there is a strong temp-

tation to increase the number of articles and thus the income through lower quality requirements. This threat exists for all publishers – even serious ones. However, it has increasingly been systematically exploited by newly founded journals to fraudulently penetrate the journal market and to urge authors under systematic deception regarding the nature of their journals to publish in predatory journals. One means of doing this is to write to scientists by e-mail, as described in this article. Despite assertions to the contrary, there is no quality control of the content of submitted manuscripts; practically everything that is sent in is published.

One would think that science is critical and robust enough to resist these developments. But this is precisely not the case, as a study in Germany in July 2018 showed. *Norddeutscher Rundfunk* (Northern German Broadcasting), *Westdeutscher Rundfunk* (West German Broadcasting) and the Munich-based daily newspaper *Süddeutsche Zeitung* identified 5000 scientists from the established scientific community and from the health care sector who had published in such dubious journals. The reaction to this disclosure was limited, and it did not

seem to affect the scientific community in particular [2]. In Germany, interest was by no means as high as in the USA or India, for example.

The COVID-19 pandemic has created a completely new situation. Due to the large number of open questions about coronavirus disease that need to be answered scientifically, many research projects have been started within a very short period of time. This has resulted in a high number of publications. It seems, however, that the conditions of the pandemic have been accompanied by a loss of quality in science. One of the regularly criticized points is the peer review process, which has come to public attention with a bang following the withdrawal of articles by *The Lancet* [5] and the *New England Journal of Medicine* [4] on the treatment of COVID-19 with the anti-malarial drug chloroquine. Although these publication failures, which put the quality standards and credibility of science under massive pressure, have no direct connection to predatory journals, they do indirectly, because the hitherto deep quality gap between the two worlds – here: serious scientific journals, there: windy pseudo-journals – is becoming shallower. The personal observation of the authors of this article shows on the basis of the e-mails received that the activities of predatory journals continue unabated, now also in the corona environment [3].

Recommendations

Even if the possibility cannot be excluded that among the senders of unsolicited e-mails are some (albeit few) reputable publishers or journals, the recipients are generally well advised not to react to this type of mails. More and more (not only medical) faculties and institutions explicitly point out that publishing in these journals is contrary to the principles of good scientific practice. The following websites can be useful in this context:

- Wikipedia: Predatory publishing. <URL: https://en.wikipedia.org/wiki/Predatory_publishing#Other_lists>
- Howard-Tilton Memorial Library, Tulane University, New Orleans, Louisiana, USA: Predatory Pub-

Specific request

"As we are planning to accomplish the Volume 3 Issue 5 by the end of January in our [journal], but we are in deficit of articles for this issue. Hence, we require your voluntary contribution at least 2500–4000 words of article based upon your research interest. I hope, 2page article will not a big task for distinguished people like you. Envisaging to have your precious manuscript by this weekend."

"Hence we have selected some eminent authors like you to support our journal. We kindly request you to submit any type of your manuscript towards our journal and help us to reach the target for our next issue."

"This is a follow up mail from the Editorial Office. We would be glad to know your opinion to submit your manuscript for the upcoming issue of the journal, so that we can plan accordingly to include it in the same."

"I know you are busy. So i wanted to reach back out about my earlier request-have you had a chance to review the invitation that i sent over a couple of weeks ago."

"We are in need of one article for successful release of Volume 4 Issue 4 by 4th February? Is it possible for you to support us with your 2 page opinion/case report or mini review, we hope 2 page article isn't time taken for eminent people like you. We hope you won't disappoint us. Acknowledge this email within 24hrs."

Table 6 Examples of time-bound requests (partly in incorrect English)

(Tab. 1–6: JC Türp)

lishers. A Guide. <URL: <https://predatoryjournals.com/journals/>>

- Think. Check. Submit. <URL: <https://thinkchecksubmit.org/>>
- Stop Predatory Journals: List of Predatory Journals. <URL: <https://predatoryjournals.com/journals/>>

If these hints are not followed, one may well end up like a French doctor and researcher from Marseille who wrote in frustration on 15 February 2020 on the social networking site ResearchGate:

*Dear all
wish I saw this earlier
we paid for the fees
and the paper appears nowhere else than
on their website
No answer to my emails
don't think it's possible to get the money
back*

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4. Rubin EJ: Expression of Concern: Mehra MR et al. Cardiovascular disease,

drug therapy, and mortality in Covid-19. N Engl J Med 2020; 382: e102

5. The Lancet Editors: Expression of concern: Hydroxychloroquine or chloroquine with or without a macrolide for treatment of COVID-19: a multinational registry analysis. Lancet 2020; 395: e102

6. Türp JC: "Once around the world ...". Unsolicited congress invitations via e-mail. Dtsch Zahnärztl Z Int 2020; 2: 56–61



(Photo Basliak, Basel)

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Are zirconias of today different?



Background

The advantages of ceramic materials are generally considered to be their tooth-like translucent appearance, their good biological compatibility in direct contact with the gingiva and a wear pattern that is comparable to that of enamel. These criteria are usually met by lithium silicate ceramics, which are indicated for veneers, tabletops, single crowns and small anterior bridges. If we wish to expand the indication range and integrate larger restorations in the posterior region, this objective is only achievable with zirconia ceramics [7]. However, the higher fracture strength

of zirconia is obtained at the expense of an opaque, less tooth-like appearance. This fact was initially not disturbing because the opaque framework was veneered with feldspathic ceramics. Since it has become technically possible, using the CAD/CAM process, to produce not only frameworks made of zirconia, but also complete restorations with occlusal surfaces, the high opacity of zirconia is no longer desirable from a clinical point of view. Developments in recent years have aimed to develop zirconias with the above-mentioned properties of silicate ceramics, which include combining translucency, bio-

compatibility, a tooth-like wear pattern with higher fracture strength and the possibility of CAD/CAM processing. These efforts have resulted in the development of different types of zirconia.

The crystal structure of zirconium dioxide (Fig. 1, Fig. 2) can be influenced by doping it with different amounts of yttrium and/or aluminum [13]. Zirconia exists in varying phases which depend on temperature; these are the cubic (> 2370°C), tetragonal (> 1170°C) or monoclinic (room temperature) phases; moreover, phase transitions are accompanied by a change in volume. In the case of opaque “conventional zirconia”, for example, tetragonal fractions can be stabilized at room temperature by doping them with 3 mol% yttrium oxide (3Y-TZP, 3 mol% yttria stabilized tetragonal zirconia polycrystal). This allows a spontaneous phase transformation to take place within the monoclinic crystal structure in response to mechanical stress. The increase in volume that occurs can, for instance, counteract the propagation of cracks.

Today we distinguish several generations or classes of zirconia [13]:

- 1st Generation 3Y-TZP-A → flexural strength > 1000 MPa → opaque
- 2nd Generation 3Y-TZP-LA → flexural strength 900 MPa 5 % → more translucent
- 3rd Generation 5Y-TZP → flexural strength 600 MPa 15 % → more translucent
- 4th Generation 4Y-TZP → flexural strength 750 MPa 10 % → more translucent

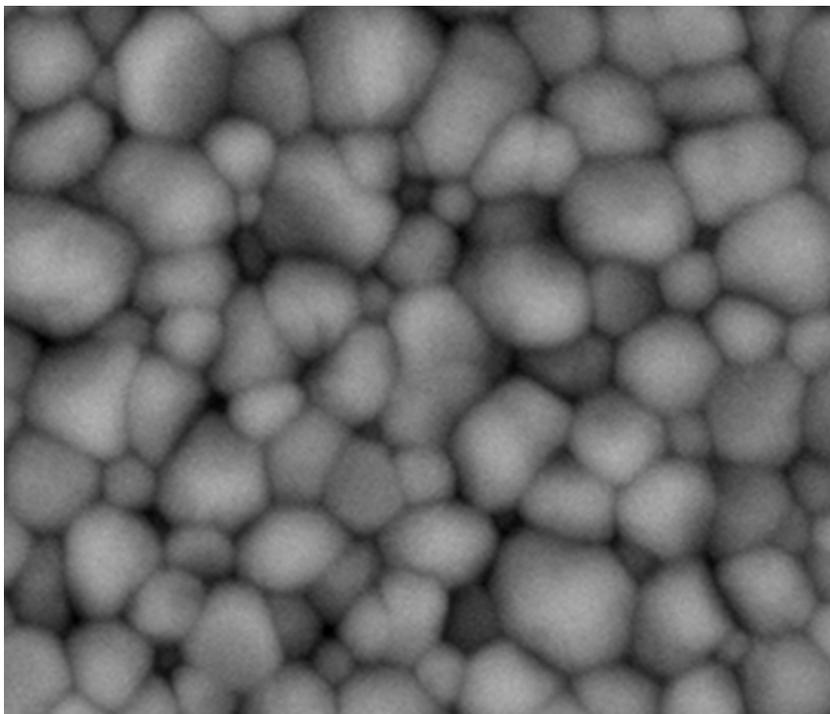


Figure 1 Scanning electron microscope imaging of the surface of 3Y-zirconia (magnification: 10,000x)

Translation from German: Cristian Miron

Citation: Behr M, Füllerer J, Strasser T, Preis V, Zacher J: Are zirconias of today different? Dtsch Zahnärztl Z Int 2020; 2: 114–118

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- 5th Generation 3Y/4Y/5Y-TZP → flexural strength 550–1200 MPa
1–15 % → more translucent (Multilayer with translucency gradients)

In a first step to make 3Y-TZP more translucent, the aluminum content was reduced in the 2nd generation. Yet, only the 3rd and 4th generations of zirconia show considerably improved translucency. However, they achieve higher translucency at the expense of lower strength, with values being similar to those of lithium disilicate ceramics. The newest development in zirconias are “Multilayer”; they combine areas of “highly” translucent and opaque zirconium dioxide in several layers within the same milling block (Fig. 3). By skillfully aligning the digitally planned restoration in the milling machine for the milling machine, larger bridges in the posterior region can also be fabricated with a more natural color gradient. However, it is important to note that the more translucent areas of the milling blocks have a lower strength than the opaquer areas. This can result in clinical failures if the mixed blank is incorrectly planned and set up in the milling machine, as though the same flexural strengths were present in all areas of the blank. Furthermore, initial investigations on the strength of various Multilayer zirconias showed that the strength in the transition layer (interphase) could be a weak point [5]. The strength of this “transition layer” was about 30 % lower than the strength of the “pure” 3Y-TZP or 5Y-TZP zirconia layers; thus, Kaizer, for instance, is of the view that the clinical indication for Multilayer should not be expanded, but rather limited [5].

Due to their opacity, 1st Generation zirconias are mainly used as framework materials. It is possible to veneer them with feldspathic ceramics in order to obtain a natural looking tooth-colored restoration. The recurrent problems with chipping, especially in combination with implant restorations [10], can be reduced through standardized and optimized processing protocols [14]. It is important to note that, in contrast to metal ceramics, the processing

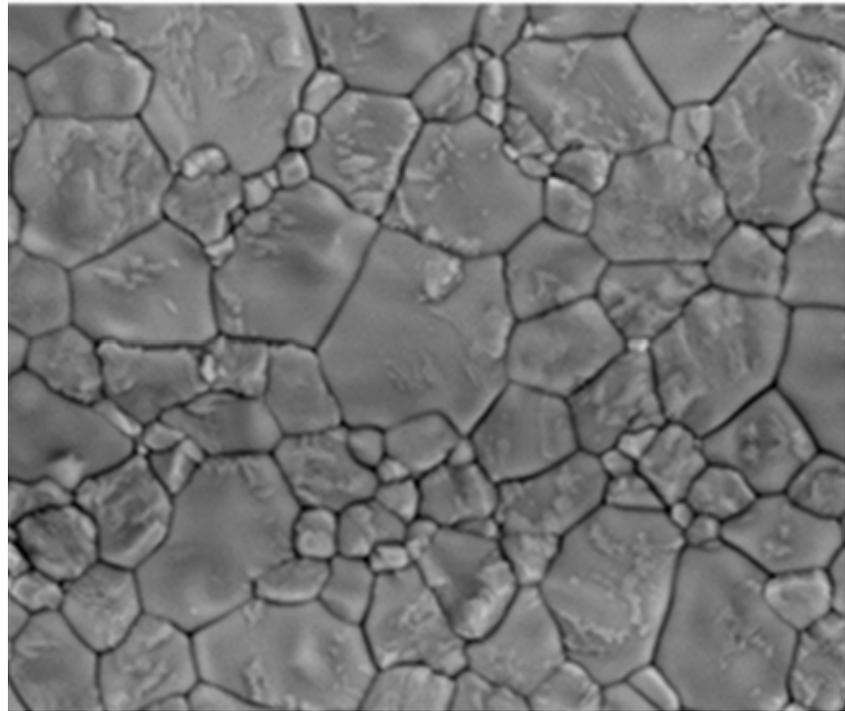


Figure 2 Scanning electron microscope imaging of the surface of 5Y-zirconia (magnification: 10,000x). Note the larger particle size compared to 3Y-zirconia (Fig. 1).

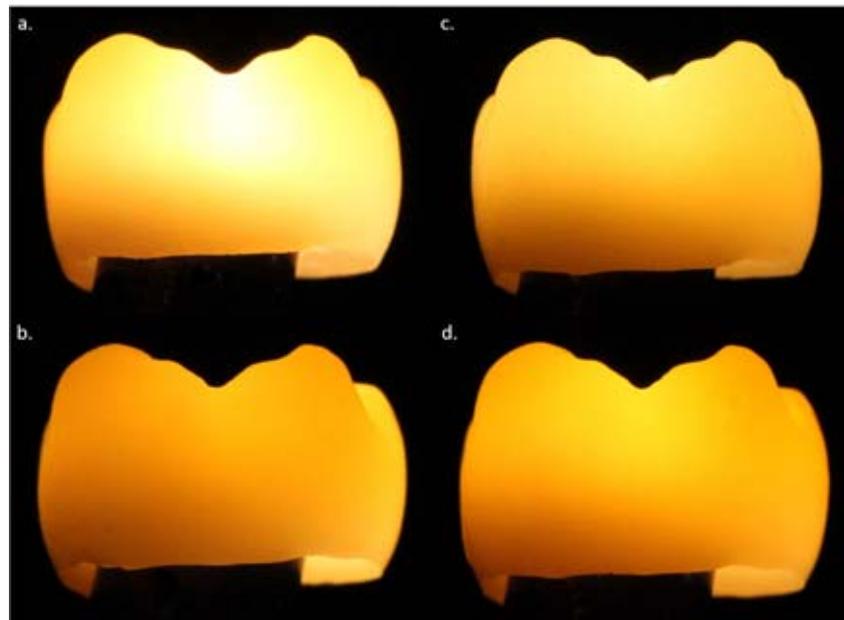


Figure 3a–d Illustration of the different translucency degrees of different ceramic materials. This example uses a molar crown for tooth 46. View from lingual using light guide illumination. All crowns were made of different materials (a–d), but with the aid of the same digital dataset using CAD/CAM, the crowns all have identical wall thicknesses. (a) Ivoclar emax CAD (Ivoclar-Vivadent, Schaan, FL); (b) Pritidenta multidisc ZrO₂ (Pritidenta, Leinfelden, D); (c) Ivoclar emax ZIRCAD Prime (upper position in Multilayer blank selected) (Ivoclar-Vivadent, Schaan, FL); (d) Ivoclar emax ZIRCAD Prime (lower position in Multilayer blank selected) (Ivoclar-Vivadent, Schaan, FL)

possibilities of zirconia are considerably smaller. For example, local temperature increases during the grinding of metal-ceramics is relatively well distributed by the metal lattice

structure, whereby the lattice structure of the ceramic leads to high temperature gradients. Due to the large temperature differences within closely spaced crystal structures, ini-

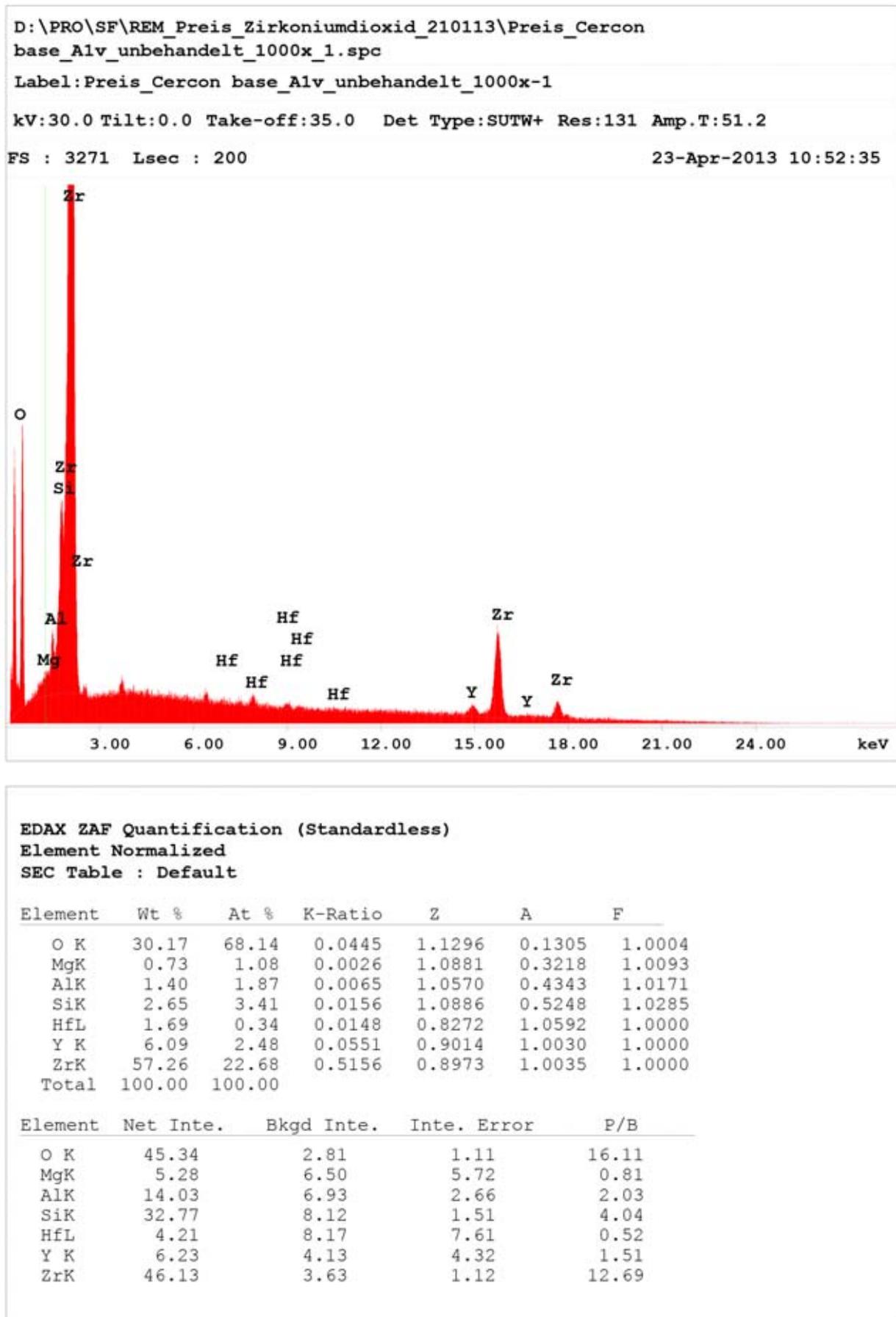


Figure 4 Plot of an EDX analysis (energy dispersive X-ray spectroscopy) of a 3Y-zirconia surface. The plot shows the chemical elements found in the sample: Zr, Al, Mg, Y, Hf, O, Si.

tial cracks form, which then propagate during the period of use, and can then contribute to premature failure, such as chipping.

Besides the clinical concerns regarding chipping, the new digital design possibilities for directly designing teeth with functional occlusal surfaces has also fuelled the desire to process esthetically appealing restorations with more translucent zirconia using a single class of materials by means of CAD/CAM. By doping zirconium dioxide with 5 mol-% yttrium oxide, abbreviated as “5Y-TZP”, this requirement is fulfilled and the translucency partially reaches that of lithium disilicate ceramics [13]. However, this advantage of increased translucency is offset by the disadvantage of reduced flexural strength, which reduces the clinical indication range of this type of zirconia. In fact, the indication range for 5Y-TZP zirconia hardly differs from that of lithium disilicate ceramics [14]. Apart from single crowns in the anterior and posterior areas, it only includes three-unit bridges in the anterior and premolar region. Bridges in molar area and the replacement of more than one pontic are usually not permitted. With 4th Generation zirconias (4Y-TZP), the strength is further increased so that a few manufacturers have expanded the indication range to include that of the molar region. In this case, in the planning phase of a restoration, the differing specifications from the manufacturers should already be taken into account.

What all zirconias have in common is that their wear pattern differs significantly from that of enamel or previous restorative materials [12, 15]; they practically do not wear. Due to this fact, if wear-resistant monolithic restorations are distributed unfavorably in the dentition, occlusal changes that affect the position of the masticatory plane may result. Thereafter, functional interferences cannot be ruled out [2]. In order to avoid damage to the antagonist teeth, it is essential to always perfectly polish monolithic zirconia to a high gloss following occlusal corrections [8, 11]. If this measure is omitted, antagonist teeth will become disproportionately damaged through abrasion [12].

Moreover, the safety of zirconia as a material in clinical applications requires attention because the starting material for clinically used zirconia is the mineral “zircon”, which is a carrier of natural radioactivity [1, 16]. Besides zirconium silicate, it contains hafnium oxide, thorium oxide and uranium oxide. These “impurities” must be removed from the material and this is achieved for thorium oxide and uranium oxide. The small traces of hafnium (Fig. 4), which usually remain detectable in zirconium dioxide, are nevertheless harmless. However, an unsatisfactory fact is that the Medical Devices Act [9] does not contain any regulations regarding the purity of zirconium dioxide used for medical purposes as of yet and that its treatment processes are not very transparent. Problems with hip joint prostheses from the 1990s show [3] that vigilance is required in this aspect.

Conclusion

Depending on their yttrium/aluminum doping ratio, dental zirconias show different properties. Zirconias with higher translucency have reduced mechanical strength compared to classical opaque zirconias. Due to this fact, their clinical indication range is limited. In fact, the clinical indications for translucent zirconias hardly differ from those of lithium disilicates. The restriction or broadening of the indication range to include the molar region must be carefully considered on a case-by-case basis in relation to the manufacturer, especially with respect to 4Y-TZP zirconias. Particularly confusing is the widely varying indication range for the new 5th Generation mixed zirconias with graded translucency within a milling block. For this generation, the indication range varies from only small three-span bridges in the anterior region [6] up to the approval of 14-unit bridges [4] (maximum of 2 teeth per dental gap replaced). Therefore, nowadays, the concept of “the zirconia” does not exist, but rather a multitude of material variants, which are created for individualized applications.

Michael Behr, Julian Füllerer,
Thomas Strasser, Verena Preis,
Julian Zacher, Regensburg

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Minimally invasive esthetic and functional rehabilitation after systematic periodontal therapy: a case report

Anamnesis: The patient was 45 years old at the time of his first consultation in 2017. He was referred for the treatment of his „progressive periodontitis“ and had not undergone previous periodontal therapy. The patient had no general diseases, took no medication and claimed to be a smoker (35 pack years). His main complaints were that he suffered from tooth hypersensitivity, tooth mobility, bleeding gums and pain on biting in the posterior right upper jaw.

Clinical findings: Oral inspection revealed generalized soft and localized hard biofilm formation. Teeth 17–26 and 38–47 were present and they responded positively to sensitivity testing and negatively to percussion. The marginal gingiva appeared slightly edematous and swollen. There were generalized probing pocket depths of more than 7 mm and localized values up to 12 mm for teeth 45 and 46. The attachment level was generally above 7 mm and locally up to 13 mm for tooth 14. Grade I–III tooth mobility and grade 1–2 furcation involvement were recorded. Tooth 22 was elongated, rotated and protruded. Panoramic X-ray imaging revealed that the alveolar ridge was located in the apical third of the roots as well as the presence of multiple areas of furcation involvement and periapical translucencies.

Diagnosis:

- Periodontitis Stage IV, generalized, grade C with modifying risk factor smoking
- Endo-periodontal lesion grade 3 at teeth 16 and 17
- Suspected endo-periodontal lesion at teeth 26, 38 and 47
- Suspected occlusal trauma at teeth 22 and 45
- Unharmonious anterior situation (multiple recessions, anterior teeth tipping towards vestibular, protrusion of tooth 22)

Therapy: The patient quit smoking until re-evaluation. Teeth with a mobility grade \geq II were splinted using composite. Root canal treatments of teeth 16, 17 and 26 as well as the functional reduction of teeth 22 and 45 were performed. Tooth 38 was extracted. Subsequently, anti-infective therapy ensued in form of a full-mouth-disinfection with adjuvant antibiotics. After re-evaluation and supportive periodontal therapy (SPT), corrective periodontal surgery of teeth with persisting probing pocket depths \geq 6mm was performed by means of distal wedge excisions, root amputations and furcation tunneling. Six months after periodontal surgery, the periodontium appeared stable. According to the

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patient, there were subjective deficiencies due to interdental black triangles, recessions and tooth tipping towards vestibular in the anterior region. Thus, direct shape corrections of teeth 14–24 and 34–44 and closure of the interdental gap between teeth 43 and 44 followed.

Conclusion: After successful periodontal treatment, functional corrections and direct restorative techniques with composite can be used even for patients with severe periodontal disease in order to achieve minimally invasive and successful treatment outcomes.

Keywords: adjuvant antibiotic administration for subgingival instrumentation; endo-periodontal lesion; endodontic therapy; direct composite splinting; resective periodontal surgery; root amputation; furcation tunneling; shape correction; tooth widening; rehabilitation; smoking cessation; esthetics

Anamnesis

General anamnesis

The 45-year-old patient was in general good health, did not take any medication, and was a current smoker (35 pack years). He had a height of 172 cm and weighed 85 kg.

Specific anamnesis

The patient presented himself in May 2017 following a referral from

his family dentist for further treatment of his advanced periodontitis. He reported sudden tooth mobility, heavy bleeding and painful gums. He suffered from pronounced hypersensitivity and from pain on biting in the posterior upper jaw. He claimed to brush his teeth twice daily with an electric toothbrush without performing additional interdental cleaning. According to his knowledge, no systematic periodon-

tal therapy had thus far been performed.

Social anamnesis

The patient was married and had 2 children. He was employed. His family history of oral disease was inconspicuous.

Patient expectations

As part of the treatment plan, the patient's primary concern was maxi-



Figure 1 Photo status of the initial situation with localized hard and generalized soft biofilm and tooth tipping towards vestibular in the upper jaw anterior region (05/2017)

mum tooth preservation and elimination of oral pain and inflammation.

Findings

Extraoral findings

The extraoral findings were inconspicuous with the lips closed. When speaking, a pronounced foetor ex ore and a lisping was perceived by the practitioner.

Intraoral findings

The mucous membranes of the pharyngeal ring, the floor of the mouth, the tongue, the hard and soft palate, the cheeks and the lips showed no pathological findings. Generalized plaque as well as tartar and edematous swellings of the gingiva in the mandibular anterior region were present. In addition, generalized stains could be determined. There were 28 teeth present. Teeth 18, 27, 28 and 48 were missing. Teeth 17, 16, 26 and 47 were restored with direct amalgam restorations; teeth 37, 36, 35, 45 and 46 displayed direct composite restorations, which proved to be satisfactory on visual and tactile inspection. Little attrition, abrasion and erosion were found based to the patient's age. All teeth tested positive during sensitivity testing using cold

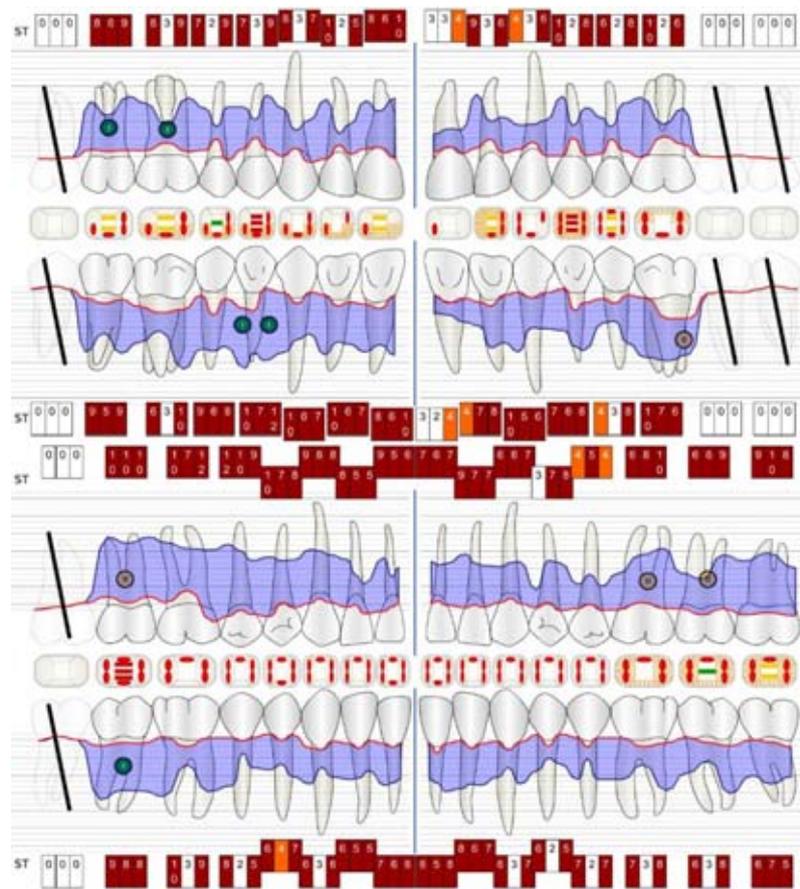


Figure 2 Initial findings with generalized probing pocket depths and attachment level ≥ 7 mm as well as generalized BOP and suppuration, mobility grade III and furcation involvement up to grade II (05/2017)

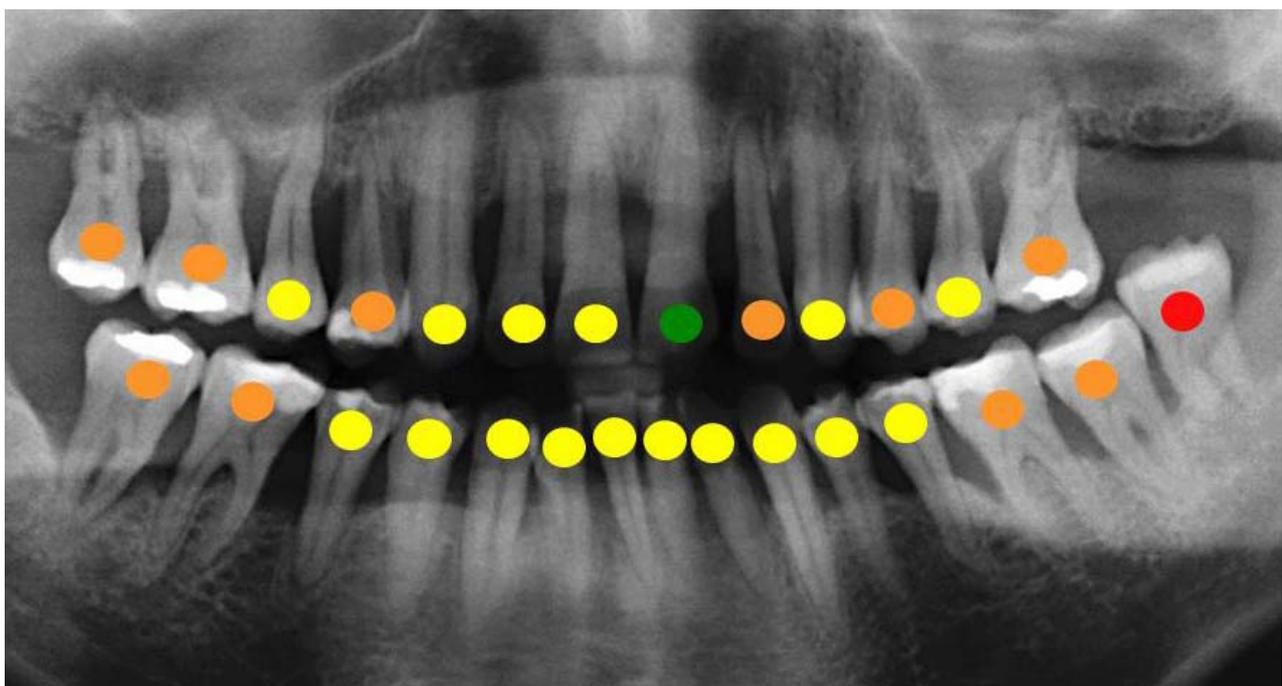


Figure 3 Panoramic X-ray (05/2017) with prognosis estimate (Kwok & Caton, 2007 [10]; prognosis gradation: green = favorable, yellow = questionable, orange = unfavorable, red = not possible)

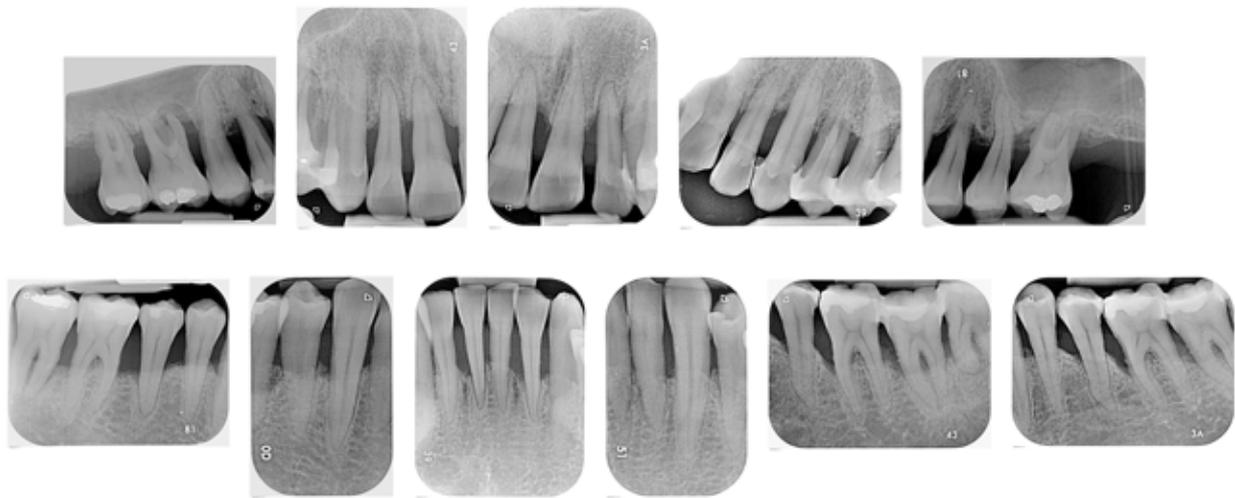


Figure 4 X-ray status with the generalized horizontal course of the alveolar ridge in the apical third of the root with apex involvement of teeth 17 and 16, furcation involvement and vertical defects (05/2017)

spray and the percussion test was negative (Fig. 1 and 2).

The probing pocket depths were 0–3 mm for 15 %, 4–6 mm for 32 % and ≥ 7 mm for 53 % of the sites. Teeth 16, 13, 12, 11, 23, 24, 26, 38, 36, 44, 46 and 47 displayed probing depths of up to 10 mm, while teeth 14

and 45 had probing depths up to 12 mm. The attachment level was 0–2 mm for 1 %, 3–4 mm for 13 % and ≥ 5 mm for 86 % of the sites. Bleeding on probing (BOP) was generalized and present for 74 % of the sites. After probing, pus discharge was observed around teeth 16–11, 22, 24,

26 and 38–36. Furcation involvement grade I and grade II was observed for teeth 17, 16 and 14 and teeth 26, 37, 36 and 47, respectively [8]. With regards to tooth mobility, teeth 15 and 37 displayed grade I, teeth 17, 16, 11, 22, 25 and 38 grade II, and teeth 14, 24 and 47 grade III.



Figure 5 Photo status at SPT II with visible attachment losses and black triangles in the anterior region as well as existing direct splints (03/2018)

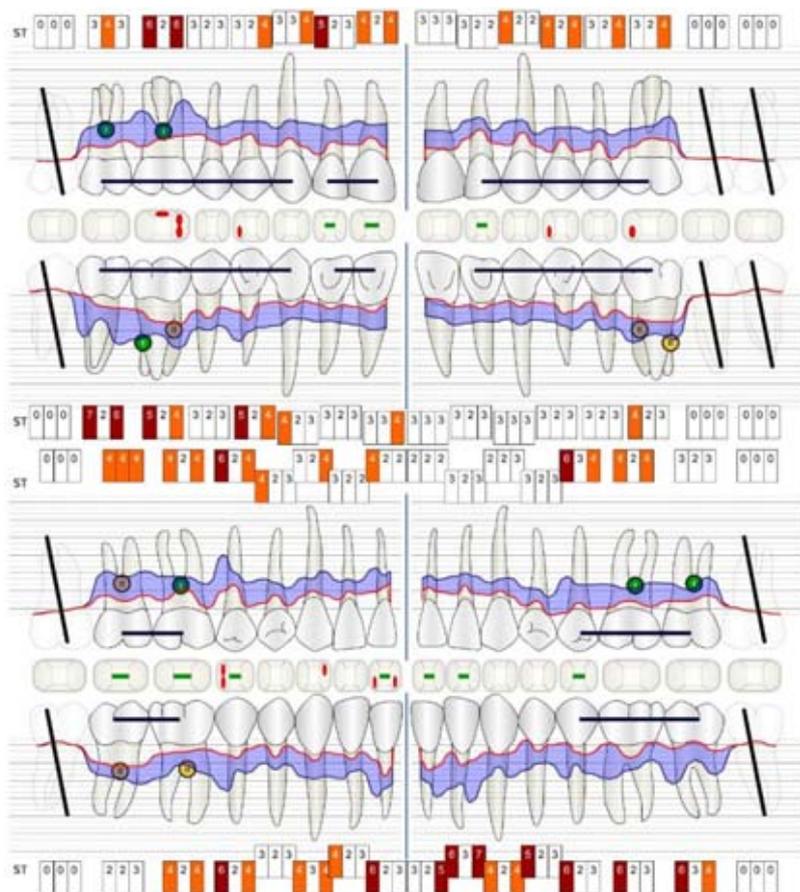


Figure 6 Findings at SPT II with generalized probing pocket depths ≤ 3 mm as well as localized BOP, mobility up to grade I and furcation involvement up to grade II (03/2018)

Radiological findings

In the panoramic X-ray image from 05/2017, the horizontal course of the alveolar ridge in the upper jaw was seen to be in the apical third of the root and in the lower jaw, in the middle to apical third of the root. Interradicular translucent areas that indicated furcation involvement were observed for the teeth 17, 16, 14, 24, 26, 38–36, 46 and 47. Periradicular translucencies extending to the radiological apex were observed on teeth 17, 16 and 26. The temporomandibular joints were symmetrical and the ventilation in the maxillary sinuses was equal as far as it could be assessed (Fig. 3).

In the X-ray status from 05/2017, additional periradicular translucencies were observed which indicated vertical bone defects around teeth 14, 24, 36 and 35. Periradicular translucencies corresponding to widened periodontal spaces were noticeable around teeth 22 and 45. Teeth 15–25 and 37–47 displayed no pathological findings at the root apices (Fig. 4).

Diagnosis

- Periodontitis stage IV, generalized, grade C with modifying risk factor smoking [13]
- Endo-periodontal lesions grade 3 on teeth 16 and 17 [13]
- Suspicion of endodontic lesions on teeth 26, 38 and 47
- Suspicion of occlusal trauma on teeth 22 and 45
- Unharmonious anterior situation (multiple recessions, anterior teeth tipping towards vestibular, protrusion of tooth 22)

Prognosis

A prognosis assessment according to Kwok & Caton, 2007 is shown in Figure 3 [9]. In this case, local factors such as attachment level, probing pocket depth, furcation involvement and tooth position were used for differentiation [9].

Therapy

Therapeutic plan

- Smoking cessation
- Endodontic treatment of teeth 16, 17 and 26
- Extraction of tooth 48
- Systematic periodontal therapy

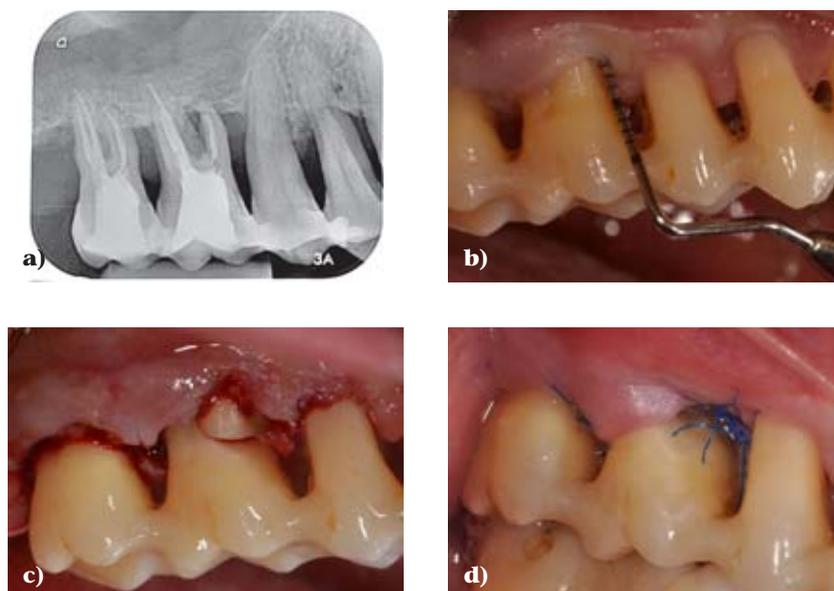


Figure 7a–d Resective periodontal surgery on teeth 17 to 15 with root amputation (mb) of tooth 16 and distal wedge excision on tooth 17 (a: endodontic therapy, b: pre-operatively, c: mesiobuccal root amputation, d: 1 week post-operatively)

- Direct composite splinting of all teeth with mobility grade \geq II
- Functional corrective measures on teeth 22 and 45
- Esthetic rehabilitation of the anterior teeth

Endodontic therapy

Teeth 17 and 16 were endodontically treated with mechanical instrumentation as part of the anti-infective therapy. The pre-surgical endodontic treatment of tooth 26 was performed after the anti-infective therapy. Before trepanation closure with composite, the root canal fillings were each shortened by about 3 mm from the canal entrance in order to guarantee separation of the roots in composite during the ensuing root amputation.

Anti-infective therapy

The patient could be convinced to stop smoking. During periodontal pre-treatment, he managed to become a non-smoker abruptly with the help of nicotine patches. The patient attended 3 oral hygiene sessions at intervals of approximately 2 weeks. In these sessions, intensive oral hygiene training with individualized interdental brushes (Curaprox CPS 14, LS 635G, LS 636, Curaden Germany GmbH, Stutensee, Germany), which were adapted

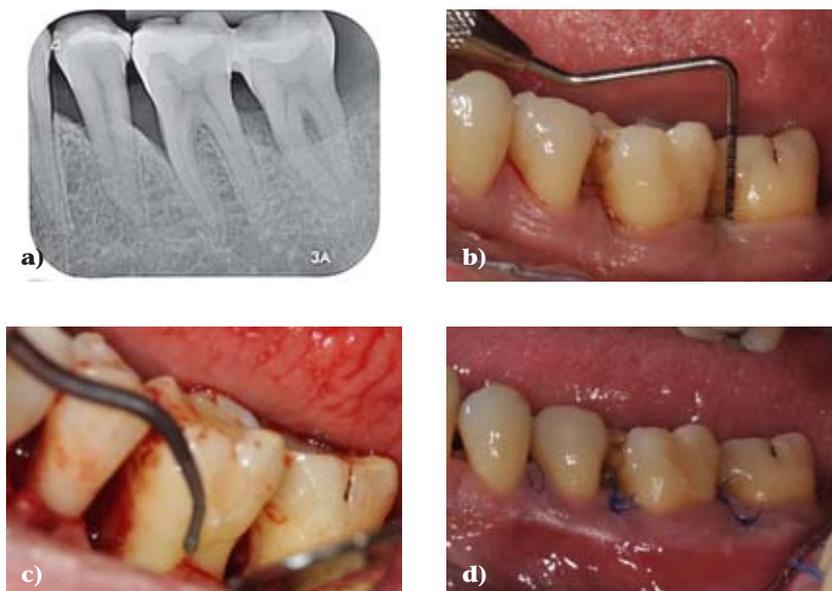


Figure 8a–d Periodontal surgery on teeth 37 to 34 with subtractive odontoplasty in the furcation area of tooth 36 (**a**: X-ray imaging of initial situation, **b**: pre-operatively, **c**: odontoplasty + distal root amputation, **d**: 1 week post-operatively)

to his interdental spaces, took place and the parameters Plaque Control Record (PCR according to O'Leary, 1972) and Gingival Bleeding Index (GBI according to Ainamo & Bay, 1975) were recorded [2, 12]. The GBI was between 1 % and 0 % in each case and the PCR could be improved from 61 % to 14 % over the course of the sessions. All teeth with a mobility grade \geq II were splinted directly with composite (teeth 17–13,

12–11, 22–27, 37–36 and 45–47). The functional contact relations of teeth 22 and 45 were corrected by selective reduction.

Subgingival scaling and root planning (SRP) was performed for each half of the mouth as part of a full-mouth disinfection (FMD) on 2 consecutive days [18]. Due to the endo-periodontal lesions and the recently performed root canal treatments, teeth 17 and 16 were only instrumented in the coronal third of the root in order to not endanger the endodontic regeneration potential of the apical root areas [16]. Tooth 48 was extracted during the FMD. Subsequent to SRP, chlorhexidine gel (1 %) was applied to the treated pockets. An adjuvant systemic antibiotic was prescribed – 375 mg amoxicillin and 250 mg metronidazole

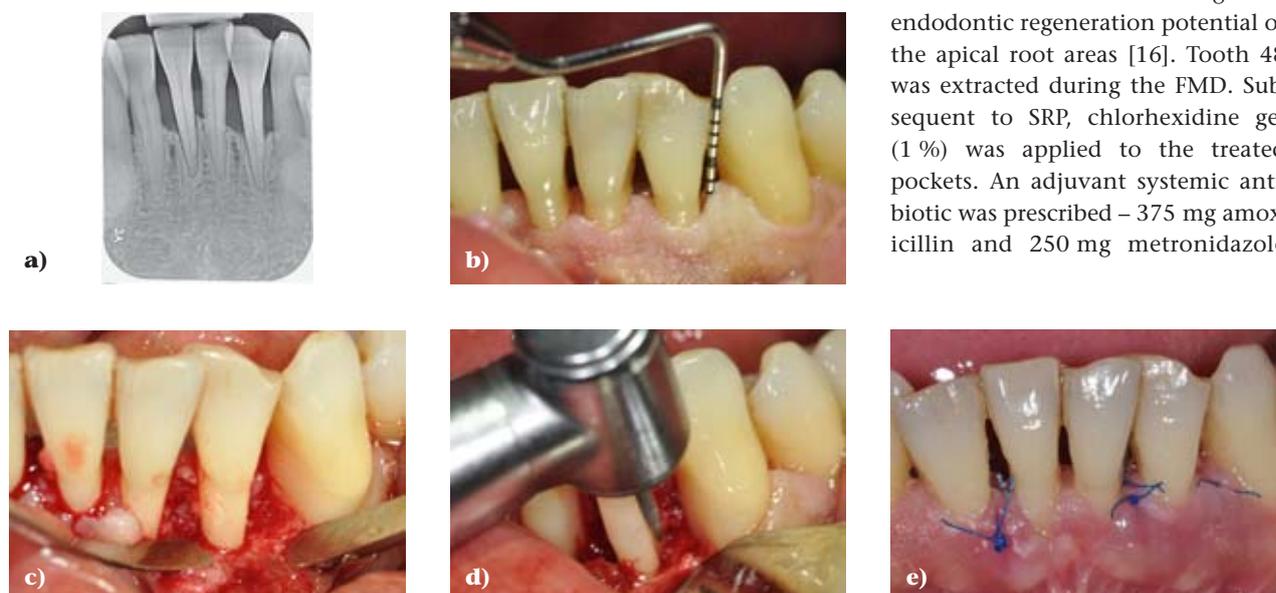


Figure 9a–e Periodontal surgery on teeth 33 to 31 with subtractive measures of root reduction on tooth 32 and periodontal surgery on teeth 41 to 42 (**a**: X-ray imaging of initial situation, **b**: pre-operatively, **c**: defect and root surface cleaned, **d**: odontoplasty, **e**: 1 week post-operatively)

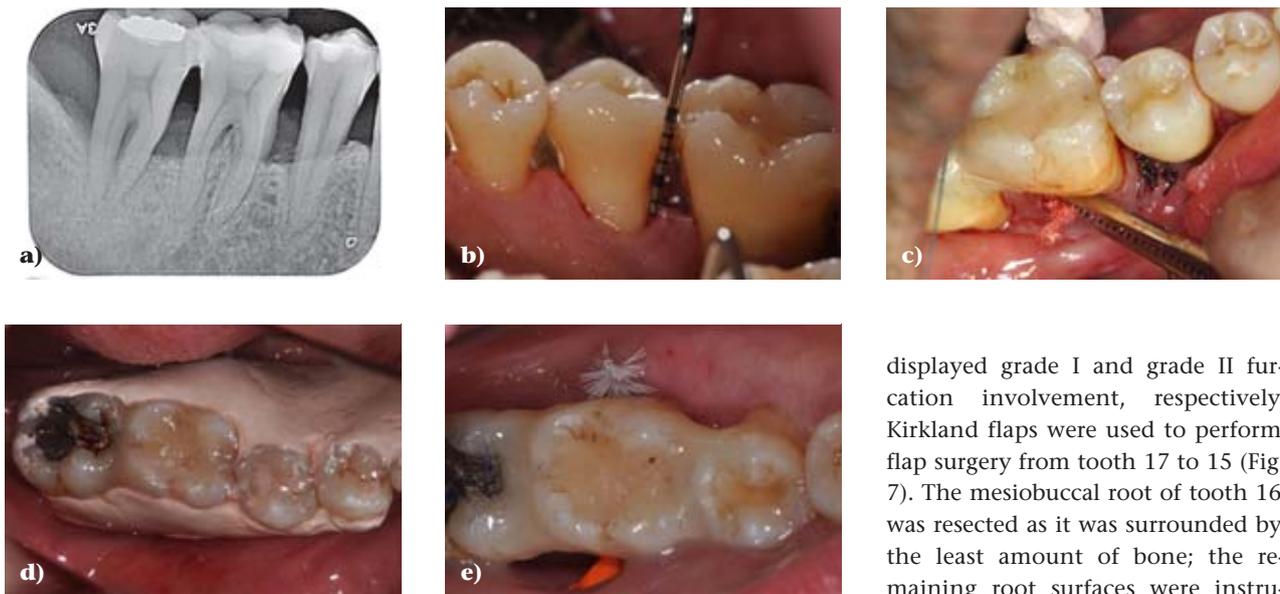


Figure 10a-e Periodontal surgery on teeth 44 to 47 with tunneling of the furcation of tooth 46 (a: X-ray imaging of initial situation, b: pre-operatively from lingual, c: tunneled furcation area traversed with gauze bands, d: gingival dressing, e: 1 week post-operatively with adapted interdenal brushes in the furcation)

3 times daily for 7 days [1]. The patient was instructed to rinse the oral cavity twice daily with chlorhexidine mouthwash (0.2 %, alcohol-free) for the following 2 weeks and to brush the teeth with chlorhexidine gel (1 %) before using the interdental brushes. One week later, a follow-up examination was performed; the gingiva appeared inconspicuous and another subgingival instillation of chlorhexidine gel (1 %) was applied into the treated pockets. Another week later, a second follow-up examination was performed and the findings were again inconspicuous. The resulting chlorhexidine stains on the tooth surfaces were removed by polishing.

Reevaluation/supportive periodontal therapy (SPT I)

The patient came for re-evaluation/SPT I 3 months after SRP. Subjectively, he reported a perceived clear improvement in the periodontal situation with no recurrent inflammation or bleeding.

The probing pocket depths were 1–3 mm at 60 %, 4–6 mm at 36 % and ≥ 7 mm at 4 % of the sites. The attachment level was 0–2 mm at 4 %, 3–4 mm at 31 % and ≥ 5 mm at 64 % of the sites. Bleeding on Probing (BOP) was recorded for 12 % of

the sites. Grade I furcation involvement was present at teeth 17, 36 and 46, while grade II was observed at teeth 16, 26, 37 and 47. Teeth 12–22, 35, 32–42 and 45 exhibited grade I mobility. The mobility of teeth 22 and 35 resulted from fractures of the composite splints. These were repaired with composite during treatment. The sensitivity test using cold spray was negative on the endodontically treated teeth 17 and 16 and positive on all other teeth, while the percussion test was negative for all teeth. Supragingival and subgingival scaling of all recessed pockets ≥ 4 mm with BOP was performed. The root surfaces of teeth 17 and 16 were also instrumented to the bottom of the pockets at approximately 7 months after endodontic therapy. The periodontitis risk assessment modified according to Ramseier & Lang 1999 showed a high risk of periodontitis; thus, a 3-month SPT interval was recommended [15].

Corrective surgical therapy

Prior to corrective surgical therapy, SPT II (approximately 6 months after FMD) was awaited (Fig. 5 and 6).

Probing pocket depths of up to 6 mm at tooth 16 and 7 mm at tooth 17 were still present. Teeth 17 and 16

displayed grade I and grade II furcation involvement, respectively. Kirkland flaps were used to perform flap surgery from tooth 17 to 15 (Fig. 7). The mesiobuccal root of tooth 16 was resected as it was surrounded by the least amount of bone; the remaining root surfaces were instrumented under direct vision and the furcation entrance between the palatal and distobuccal roots was levelled by subtractive surgery. The tooth was reduced from functional occlusion to counteract extraaxial loading. A distal wedge excision was performed at tooth 17. The wound was closed with single button sutures (5–0 Prolene). Seven days later, the wound was checked and the sutures were removed. The patient was symptom-free and wound healing progressed concordantly.

Teeth 37–35 showed mesial probing pocket depths of up to 6 mm with grade I furcation involvement at teeth 37 and 36. A flap operation was performed using a Kirkland flap with subtractive odontoplasty of the furcation area on tooth 36 (Fig. 8). Wound closure was performed using 5–0 Prolene. The sutures were removed one week post-operatively.

Teeth 31 and 41 showed persistent, localized probing depths of up to 7 mm. A flap operation on tooth 32 using a Kirkland flap and subtractive root reduction measures ensued (Fig. 9). The sutures (5–0 Prolene) were removed one week post-operatively.

Tooth 45 still had a probing depth of up to 6 mm. Teeth 46 and 47 displayed furcation involvement up to grade II. A flap operation was performed at teeth 47 to 45. Schluger and Sugarman files for the tunneling (Hu-Friedy Mfg. Co., LLC., Frankfurt am Main, Germany) of the furcation of tooth 46 were used, while subtractive measures of the furcation area on

tooth 47 were performed (Fig. 10). After primary wound closure (4–0 Ethibond), a gum dressing was applied in the created tunnel and pericoronally. One week post-operatively, the gum dressing and sutures were removed and an interdental brush (Curaprox, CPS 14) was adjusted to fit in the tunnel for daily hygiene.

Tooth 26 showed furcation involvement up to grade II. A flap operation was performed with amputation of the two buccal roots of tooth 26 (Fig. 11). The wound was closed with 5–0 Prolene. In order to minimize extraaxial loading, the height and width of the tooth crown was reduced towards the buccal direction. One week post-operatively, wound healing progressed concordantly.

Esthetic and functional rehabilitation

Stable periodontal conditions were seen at SPT III. However, the patient was not definitively satisfied with the esthetic and functional consequences of his periodontal disease and its therapy. Subjectively, he was disturbed by the black triangles, the tooth tipping towards vestibular of the maxillary anterior teeth, and especially, the elongated, extruded and rotated tooth 22. Phonetic impairments existed in the form of lisping and the patient stated that he often spat while speaking. Although hypersensitivity was improved by local fluoridation measures, it was still noticeably present. Tooth 22 continued to display an interference contact during protrusive movements.

A wax-up was used to aid the patient in visualizing the intended result of the treatment and a silicone key was made from it. While being kept relatively dry, the enamel of teeth 14–24 and 34–44 was sandblasted with aluminum oxide powder, etched, and then primer and adhesive (Optibond FL) were applied and light-cured. Using the individualized direct veneering technique, the tooth shape and position were corrected with composite (Tetric Evo Ceram, Dentin & Enamel, A3 & A2). In this way, the existing rotations, protrusions and elongations were compensated and the gaps were completely closed. Tooth 22 was reduced

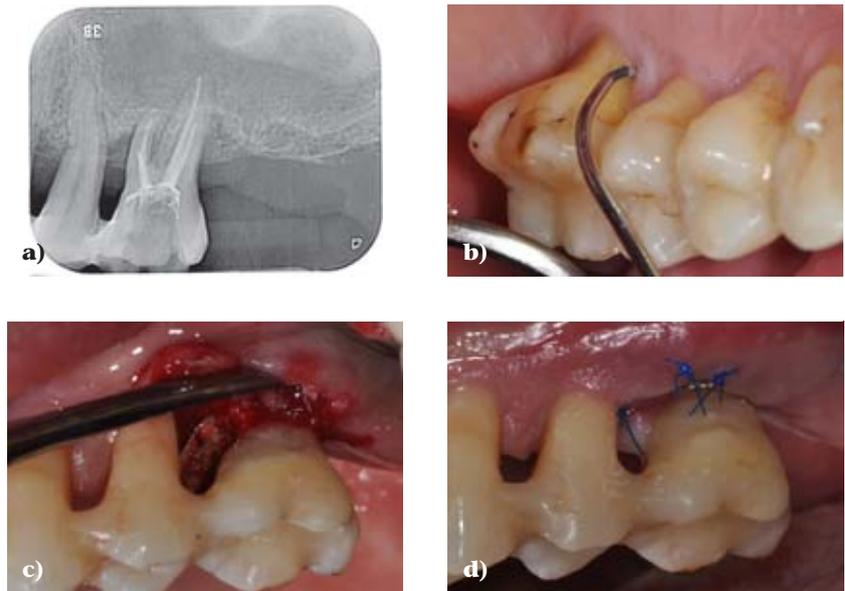


Figure 11a–d Resective periodontal surgery on teeth 25 to 26 with root amputation (mb + db) of tooth 26 (a: endodontic therapy, b: pre-operatively, c: mesio Buccal and distobuccal root amputation, d: 1 week post-operatively)

to such an extent that the functional interference contact was eliminated. The final tooth shape adjustments and high-gloss polishing took place in a second appointment. First, macrostructures were integrated by vertical indentations of the labial surfaces and the transitions of the proximal areas were designed with Soflex discs. Subsequently, the high-gloss polishing was carried out using silicone polishers and precisely fitting interdental brushes (Fig. 12 and 13) were selected.

Supportive periodontal therapy

The patient appeared regularly for SPT. Every 3 months he received a professional teeth cleaning and oral hygiene instructions. The GBI was 0 % and the PCR ranged between 15 and 44 %. Every 6 months a dental examination was performed; the periodontal status was determined and subsequent subgingival instrumentation of sites where increased probing pocket depths existed was carried out. The patient reported having the feeling of a stable absence of inflammation during the SPT. However, during the SPT phase, he started smoking again (approximately 10 cigarettes/day) and attributed this to increased stress levels and a supposedly stable oral health.

In SPT III, the probing depths were 1–3 mm at 88 % and 4–5 mm at 12 % of the sites, respectively. BOP was present at 6 % of the sites.

At SPT IV in 07/2019, the probing depths were 1–3 mm at 94 % and 4 mm at 6 % of the sites (Fig. 14 and 15). The attachment level was 0–2 mm at 15 %, 3–4 mm at 42 % and ≥ 5 mm at 43 % of the sites. BOP was observed at 9 % of the sites. Tooth 46 showed grade III furcation involvement with functional home-based hygiene. Teeth 17, 16, 14, 24, 37 and 36 continued to show grade I furcation involvement. Teeth 12, 11, 22 and 32–41 exhibited grade I mobility. The sensitivity test using cold spray was negative on the endodontically treated teeth 17, 16 and 26, but positive on all other teeth, while the percussion test was negative on all teeth. Due to the enlarged interdental spaces in the posterior region and reduced interdental spaces in the anterior region, the interdental brushes also had to be adapted based on their corresponding PHD values (PHD = passage hole diameter) (Curaprox CPS 12, 15; TePe grey, black, TePe D-A-CH GmbH, Hamburg, Germany). The periodontitis risk assessment modified according to Ramseier & Lang, 1999 indicated a medium periodontitis risk. Thus, a 6-month SPT interval was recommended (Fig. 16) [15].

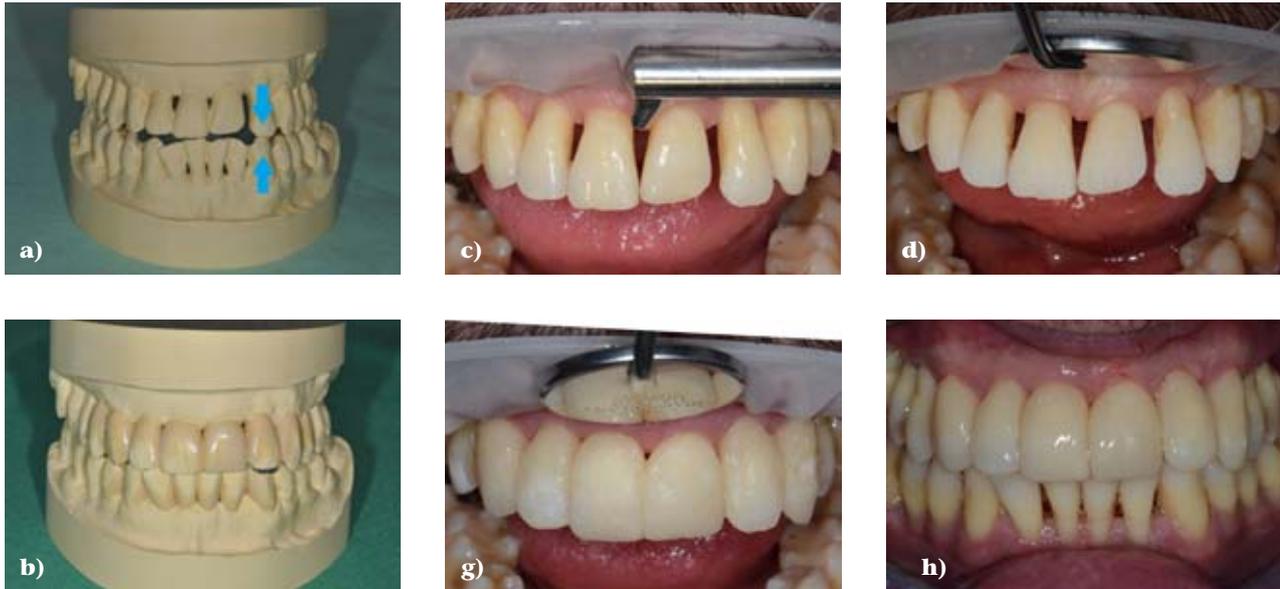


Figure 12a-j Shape corrections of teeth 14–24 and 34–44 (**a**: functional interference contact on tooth 12, **b**: wax-up, **c + d**: teeth sandblasted, **e**: incisal silicone stop, **f**: edge build-up, **g**: composite layering, **h + i**: composite finishing, **j**: polishing)

Epicrisis

The initial diagnosis was based on the masticatory dysfunction due to the existing tooth mobility \geq grade II and tooth tipping towards vestibular in the upper front area [13]. Since the attachment level at more than 30 % of the teeth was \geq 5 mm approximately, a generalized extent was observed [13]. As the primary criterion for determining the grading, the bone resorption index could be calculated as indirect evidence [13]. This was $>$ 1.00 (tooth 16: 100 % bone resorption/45 years of age), so that a

rapid rate of progression (grade C) could be assumed [13]. In addition, initial smoking \geq 10 cigarettes/day constituted a modifying factor for the classification as grade C [13].

Diagnosis of grade III endo-periodontal lesions was based on the presence of deep periodontal pockets on more than one side of each tooth [13]. The appraisal of teeth 26, 38 and 47 was in this respect more critical. Although the advanced periradicular bone loss as seen in the X-ray was indicative of an endo-periodontal lesion, the teeth reacted posi-

tively to sensitivity testing and did not show any signs of pulpitis.

The decision to use adjuvant antibiotics was made in accordance with the current S3 guideline of the DG PARO/DGZMK [1]. Since the probing pocket depths at over 35 % of the measured sites were \geq 5 mm and the patient was \leq 55 years old, it was possible to prescribe systemic antibiotics [1]. The selection and dosage chosen here corresponds to the original recommendation for the „Van Winkelhoff cocktail“. The current S3 guideline specifies a dosage of 500 mg amoxicillin and 400 mg metronidazole [1].

By preserving the teeth, including the ones with an unfavorable prognosis, the patient could achieve a state of periodontal stability. Figure 17 shows the changes in probing pocket depth and attachment level at SPT IV compared to the initial situation.

As an alternative treatment, the planning of a removable denture would have been possible. Due to the generally advanced loss of attachment and the questionable value of the abutment teeth, this may have possibly implied the complete extraction of teeth in the upper jaw. Individual periodontally compromised teeth could have been retained in situ during the fabrication of a cover denture. The patient declined this treatment option due to his young



Figure 13a-d Anterior esthetics before (**a, b**) and after shape corrections (**c, d**)



Figure 12a-j Shape corrections of teeth 14–24 and 34–44 (a: functional interference contact on tooth 12, b: wax-up, c + d: teeth sandblasted, e: incisal silicone stop, f: edge build-up, g: composite layering, h + i: composite finishing, j: polishing)

age and the desire to preserve his teeth and be treated with a fixed restoration.

The prognosis for the success of resected molars is well documented

[3–6]. In a dental office setting, Fugazzotto showed a cumulative success rate over 15 years of 96.8 % for resected molars compared to 97 % for implants in the molar region [6].

According to Alassadi et al., the main reasons for the possible extraction of a resected molar are fractures (39.5 %), caries (26.3 %) and periodontal causes (23.7 %) [3].

The patient’s compliance during SPT and the adequate home-based hygiene were the basis for why the tunneling of the resected maxillary molars could be achieved successfully [11, 17]. Regular fluoridation of the furcation areas should also be carried out in the future in order to prevent caries occurrence on the exposed root surfaces where the caries risk is high [10].

The patient’s desire for esthetics in the anterior region could be fulfilled by means of form corrections. In a study conducted in more centers, the functional and overall survival rates of shape corrections were over 98.5 % after 10 years and 77.6 % after 15 years [19]. Chipping fractures were identified as the most frequent adverse occurrences [19]. The periodontal parameters (probing pocket depth, attachment level, bleeding index) were also stable after a mean follow-up period of 15.5 years



Figure 14 Photo status, mostly inflammation-free with existing form corrections of teeth 14–24 and 34–44 (07/2019)

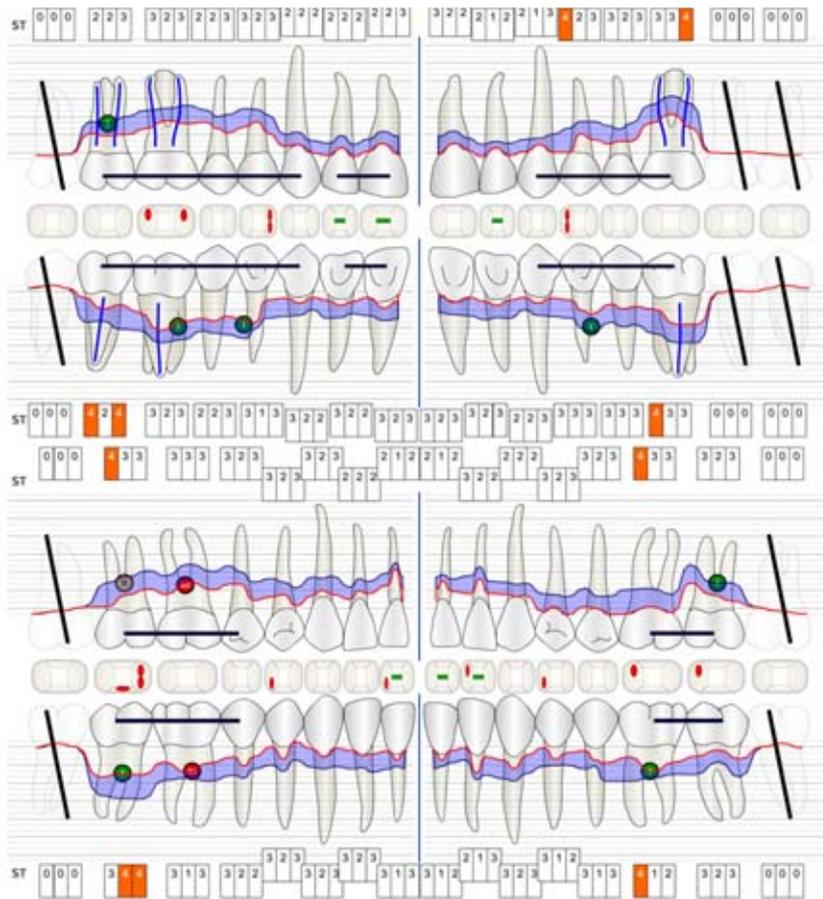


Figure 15 Findings of SPT IV with generalized probing pocket depths ≤ 3 mm as well as localized BOP, mobility up to grade I and furcation involvement up to grade III (07/2019)

and they showed no statistically significant differences compared to examinations on defined control teeth [7]. However, due to increased biofilm adhesion on aged composite material, the plaque index was slightly higher than on the natural control teeth [7].

To objectify and evaluate the success of the treatment, this patient case was evaluated according to the SSO Quality Guidelines. The results are predominantly class A [14].

Conclusion

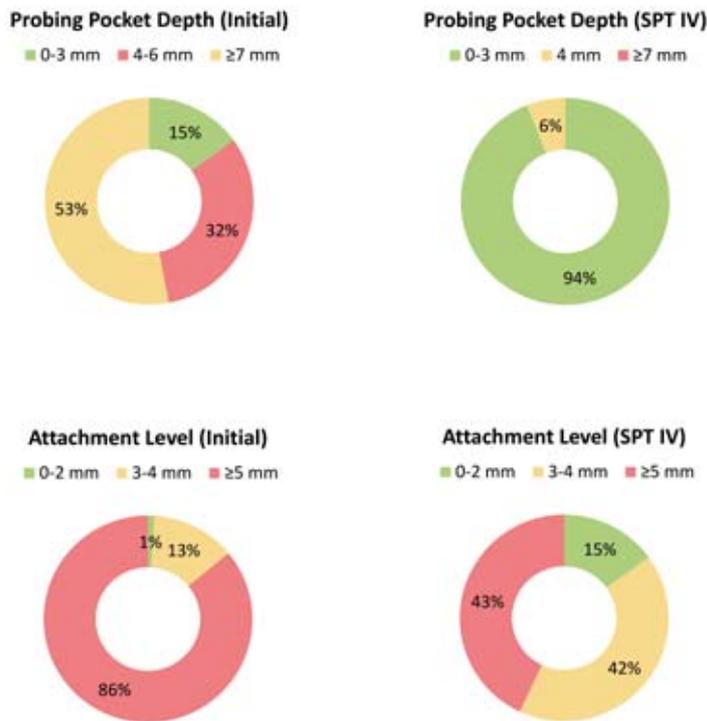
Patients with severe periodontal diseases can be rehabilitated after successful periodontal therapy by means of functional corrections and direct restorative techniques with composite. In this way, tooth substance is preserved, and to a large extent, esthetic and functional demands can be successfully fulfilled.

Conflicts of Interest

Parts of this case documentation were presented at the annual conference of the German Society of Periodontology in 2019 and a poster

	Low risk		Moderate risk		High risk	
1. Bleeding on Probing (BOP) in %	≤ 4	5–9	10–16	17–25	25–35	≥ 36
2. Number of sites with probing pocket depths of ≥ 5 mm	≤ 2	4	6	8	9	≥ 10
3. Number of teeth lost (without wisdom teeth)	≤ 2	4	6	8	9	≥ 10
4. Bone loss (Index)	≤ 0,25	0,26–0,5	0,51–0,75	0,76–1,0	1,1–1,24	≥ 1,25
5. Cigarette consumption	Non-smoker	Former smoker	≤ 10/day	10–19/day	≥ 20/day	
Preliminary risk assessment →	Low risk		Moderate risk		High risk	
6. Systemic/genetic factors: – Diabetes mellitus, – HIV-infection, – gingivo-periodontal manifestation of systemic diseases, – Interleukin-1β-polymorphism	Factor not present		Factor not recorded		Factor present	
Final risk assessment →	Low risk 1 SPT/year		Moderate risk 2 SPT/year		High risk 3–4 SPT/year	

Figure 16 Periodontitis risk assessment 07/2019 (modified according to [15])



(Fig. 1–17: A. Ciardo)

Figure 17 Comparison of periodontal parameters: Initial situation (05/2017) – SPT IV (07/2019)

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(Photo: Antonio Ciardo)

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A complex case: Ewald Harndt (1901–1996) and his relationship to National Socialism

Introduction: Ewald Harndt (1901–1996) has shaped modern German dentistry like hardly any other scientist: The leading national professional society (DGZMK) elected him its president (1957–1965), the Free University of Berlin appointed him its rector (1967–1969), and the German Dental Association (BZÄK) awarded him the Fritz-Linnert Badge of Honour (1991). He received similar awards and honours throughout the world.

Discussion: While Harndt's professional and academic achievements are undisputed, there is still a lack of clarity regarding his role in the Third Reich: On the one hand, he was dismissed in 1945 due to his membership in the Nazi Party (NSDAP), on the other hand, more recent articles point out that Harndt was considered a political suspect in the Nazi state and thus place him close to an opponent or even victim of the Nazi regime. Against this background, the present paper aims to illuminate Harndt's relationship to National Socialism. The methodological basis is a comprehensive analysis of the available archival sources and contemporary printed material and a systematic re-evaluation of the secondary literature on Ewald Harndt.

Results: It can be shown that Harndt made a number of inconsistent, false or euphemistic statements, particularly in the denazification process. The source analysis leads to the conclusion that Harndt cannot be classified as a victim but as a political follower. He was undoubtedly not a "fervent" National Socialist, but he served the regime as a member of various Nazi organizations and networks, as well as by endorsing Nazi "health policy" and using Nazi terms – notably in the fields of eugenics ("vererbt geistig minderwertige Kinder", "Unfruchtbarmachung", "Blutsverwandtschaft") and religion ("deutschreligiös").

Keywords: Third Reich; History of Dentistry; Eugenics

Introduction

The scientific and professional importance of Ewald Harndt is beyond doubt: There is hardly any important position within the university hierarchy and hardly any honour in the field of dentistry that he did not archive or receive. Even after his death he remained in the collective memory of the profession, as shown by the “Ewald Harndt Medal” last awarded in 2018.

However, Harndt’s role in the Third Reich is much less contoured: On the one hand, it is known that he belonged to the Nazi Party (NSDAP), and on the other hand, more recent essays claim that Harndt had been classified as a political suspect in the National Socialist state and had suffered repression.

But what are the historical facts? What really distinguished his personality, what was his role in the Third Reich and how did his career develop – before 1945, but also in the post-war period? Was Harndt a perpetrator or a victim, or does he evade such dichotomous categorization? These are the core questions of this paper. The first step is to trace the life and work of Ewald Harndt. In the following, the focus will be on the years 1933 to 1945 to examine Harndt’s relationship to National Socialism. Subsequently, it will be clarified how Harndt’s role in the Third Reich was perceived and evaluated after 1945 – starting with the denazification proceedings, through the laudations and obituaries up to other more recent publications that deal with his biography. In the end, concise conclusions are drawn.

Material and Methods

The study is based on several archival source collections from the Federal Archives in Berlin and the Berlin State Archives, some of which have been evaluated for the first time. Among them is also the denazification file of Ewald Harndt.

In addition, Harndt’s publications and reviews from 1933 to 1945, various directories of dentists and the “Reichsarztregister” (German medical register) were analyzed. Moreover, a systematic re-analysis of the relevant international research literature on

the life and work of Ewald Harndt and his professional environment was carried out – with a specific focus on the issues outlined above.

Results

Ewald Harndt – a brief outline of his life and work

Ewald Albert Heinrich Harndt was born on January 22, 1901 in Berlin (Fig. 1, [49]). His curriculum vitae is very well documented [2, 16, 17, 20, 53, 62–64, 66, 68, 71, 74, 75]. He was the son of the Berlin merchant Adolf Harndt and his wife Emma, née Peege [2]. Harndt grew up in Berlin, where he attended elementary school (1907–11), secondary school (1911–16) and subsequently the “Königstädter Oberrealschule”. There he passed his Abitur in 1920 [60]. In the same year he began studying medicine and dentistry in Berlin. In 1924 he passed the dental examination – also in Berlin – and obtained his license to practice dentistry. There he received his doctorate (Dr. med. dent.) in 1925 with a “histological-bacteriological study on periodontitis chronica granulomatosa”. In 1926 he passed the medical examination and obtained his license as physician.

A year earlier, in 1925, he had already founded a dental practice in a working-class district of Berlin, which, however, “had only little popularity” [64], so that he looked for alternatives. In 1926 he became a volunteer at the Surgical Clinic of the Friedrich Wilhelms University Berlin with August Bier and at the Medical Clinic with Friedrich Kraus. In 1927 he moved to the Dental Institute of the University of Berlin as an assistant, where he worked with the renowned professors Wilhelm Dieck, Fritz Williger and Hermann Schroeder. There he gained a foothold: In 1929, he obtained his second doctorate (Dr. med.) on the “Amalgam-Mercury Question”. In the year preceding the doctorate he had married Frieda Gertrud Koepnik in Berlin who bore him 2 sons – Raimund (1930–2010) and Thomas (*1932) [2]. In 1935 he became senior assistant and closest collaborator of Dieck’s successor Eugen Wannemacher. In June 1936, Harndt’s ha-

bilitation on the subject of “Rho-danide in Saliva” was completed, and in April 1938 he was appointed as a “Privatdozent” (private lecturer, comparable to associate professor) – also in Berlin. One year later, he became a “Dozent neuer Ordnung” (lecturer of the new order) – which was a better financial position –, and in 1944 he became a “außerplanmäßiger Professor” (titular professor).

After the end of the Second World War, Harndt was released from university service by registered mail from the occupying authorities (Fig. 2, [60]). In 1946, however, things went uphill again: He then became (initially provisional) head of the Department of Dental Conservation at the Dental Institute of the University of Berlin. In 1948, he was promoted to the position of regular extraordinary professor and director of the Department for tooth conservation at the Dental Institute of the former Friedrich Wilhelm University in Eastern Berlin (since 1949: “Humboldt University of Berlin”). In May 1950 he became full professor (“Ordinarius”) and director of the Dental Institute. Then Harndt decided to take a momentous step: In November 1950 he gave up his professorship in the East and moved to West Berlin, where he initially worked as a dentist in a private practice. But already in 1951 he was offered a position at the newly founded Free University (Freie Universität, FU) in West Berlin. Here he started as a lecturer, became an honorary professor in 1954 and then full professor (“Ordinarius”) for dentistry, oral and maxillofacial surgery and head of the (newly established) polyclinic of the same name in 1956. He held these positions until his retirement in 1970. Several years of work in his own dental practice followed.

Ewald Harndt died on October 11, 1996 in Bad Pyrmont – at the blessed age of almost 96 years.

At the end of his life Harndt could look back on a brilliant career with many awards and outstanding offices, which can only be addressed here in extracts: In early 1937 Harndt received the Miller Prize of the “Deutsche Gesellschaft für Zahn-, Mund- und Kieferheilkunde” (German Association for Dental, Oral and Maxillofa-



Figure 1 Ewald Harndt (1901–1996)

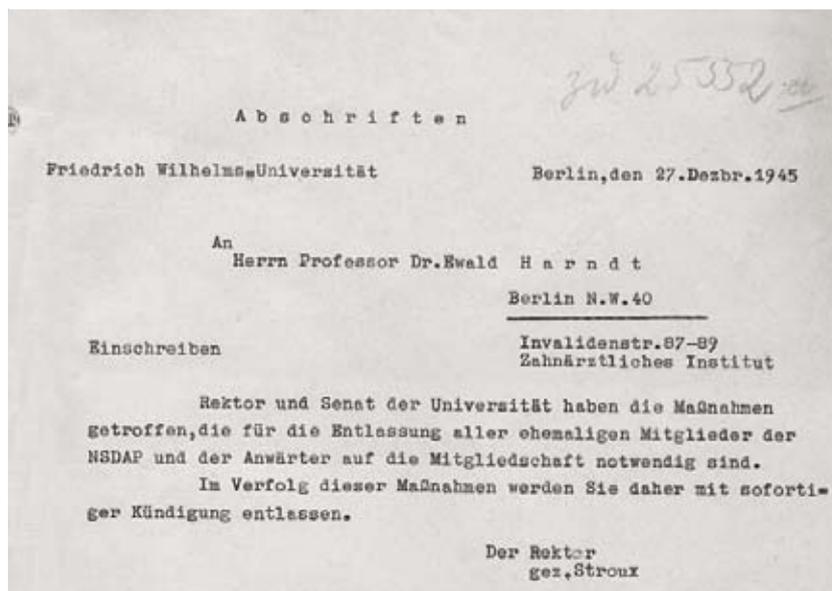


Figure 2 Dismissal of Harndt from university (1945)

cial Medicine, DGZMK) – then as now the most important scientific prize in German dentistry. From 1947 to 1968 he was an elected board member of the German “ARPA” (today: German Society for Periodontology, DGParo) and from 1949 to 1969 a board member of the DGZMK, including 8 years (1957 to 1965) as president. Harndt also was a successful editor in the post-war period: as early as 1947 he was active in this function for the DZZ (German Dental Journal – for the Berlin section, until 1964). In the same year he also became editor-in-chief of the “Forum Parodontologicum”, and from 1955 to 1976 he published the popular “Deutscher Zahnärzte-Kalender” (German Dentist Calendar).

In 1954 he received the “Jahresbestpreis” (Annual Best Price) of the DGZMK for his scientific work, in 1957 the medal of the Association Générale des Dentistes de Belgique and in 1959 the honorary membership of both the Italian Stomatological Society and the Fédération Nationale Française. Honorary memberships in the Association of Austrian Dentists (1961), ARPA Internationale (1963), American College of Dentists (1964) and DGZMK (1967) followed.

He also rose to the highest university positions: In 1961 he was elected Dean of the Medical Faculty

of the FU Berlin and in 1968 he became Rector of the university – this step undoubtedly marked the height of his career. After Oskar Römer (1928), Johannes Reinmöller (1933) and Heinrich Hammer (1958), Harndt was only the fourth German professor of dentistry to be elected rector.

This was followed in 1968 by the “Elmer S. Best Memorial Award” of the Pierre Fauchard Academy, in 1969 by the honorary membership of the German ARPA and in 1972 by that of the Association of University Lecturers in Dentistry, Oral and Maxillofacial Medicine. In 1974 Harndt received the “Goldene Ehrennadel” (Gold Badge of Honor) of the DGZMK, in 1985 the “Goldene Ehrennadel” of the “Deutsche Zahnärzteschaft” (German Dental Association), in 1987 a further honorary membership of the “Deutsche Gesellschaft für Zahnerhaltung” (German Society for Tooth Preservation, DGZ).

While a jubilee publication had been published for Harndt’s 80th birthday [53], a ceremony was held at the Charité in 1991 in honour of his 90th birthday. Now, Harndt was awarded the “Fritz-Linnert-Ehrenzeichen” (Fritz-Linnert Medal of Honor) of the German Dental Association. Finally, in 2001 a festive symposium followed in memory of

Harndt, who would have turned 100 this very year. On this occasion, the “Zahnärztekammer Berlin” (Berlin Dental Council) established the “Ewald Harndt Medal” [16, 63].

Harndt’s main areas of work and research were tooth preservation and endodontics, in particular pulpitis diagnostics and systematics as well as the principles of gangrene treatment. In the German-speaking world he became the eponym of the “Harndts Pulpitis Schema” (Harndt’s Pulpitis Scheme) [14]. In addition, he established a system of gangrene treatment, whereby he considered the latter – contrary to the common opinion of his time – also promising for molars. Besides, he dealt with cast fillings, the questionable toxicity of silver and copper amalgams, the (protective) role of saliva in cariology, gingival and periodontal diseases and oral histobacteriology and pathophysiology. Harndt was also very much in favour of retaining high-quality amalgams in dentistry. Furthermore, his animal experiments were widely recognized: Harndt fed beagles with sugar in order to investigate possible tooth damage caused by sugar intake (“sugar dogs”). His habilitation study on “salivary rhodanide” also attracted a great deal of attention – it was precisely this work that earned him the Miller Prize mentioned above [53].

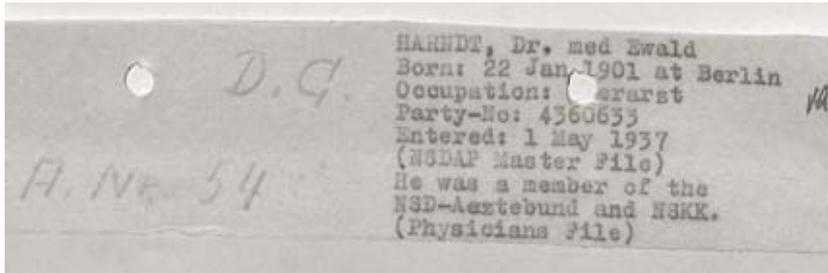


Figure 5 Proof and date of NSDAP membership including party number

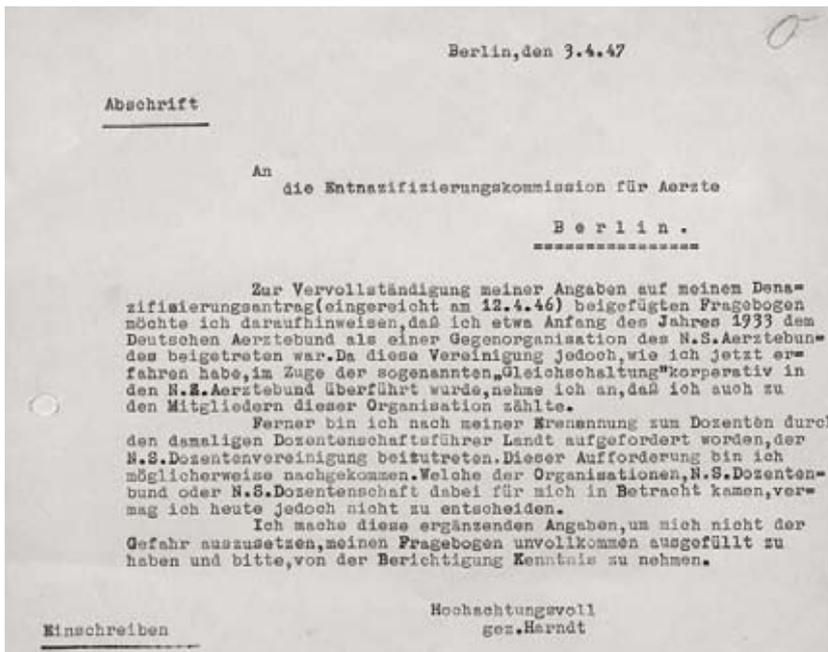


Figure 6 Revised statement regarding NS memberships

Lehrerbund" (NS Teachers' Association) and the "Reichsluftschutzbund" (Reich Air Defence Association) [4, 10]. Moreover, he became a member of the SS (Schutzstaffel, No. 460.838), where he rose to "SS Sturmabführer" (storm ban leader) in mid-September 1943. Wannemacher also held an important position within the politically centralized dental profession: In 1933 he was appointed press officer of the DGZMK, which had also been centralized. As such, he was also editor of the specialist journals "Deutsche Zahn- Mund- und Kieferheilkunde" (German Dental, Oral and Maxillofacial Medicine) and "Deutsche Zahnärztliche Wochenschrift" (German Dental Weekly). In addition, he was a lecturer at the Leader School (Führer Schule) of the German medical profession in Alt Rhese, which

had been founded as an ideological "training castle" of the NS Medical Association and opened on June 1, 1935 [9, 11].

How much Wannemacher shifted to the Nazi ideology is also shown by the fact that he left the Catholic Church in 1936 and confessed to being "gottgläubig" (believer in god) [9] – his wife did the same [10]. "Gottgläubig" was a self-designation of National Socialists who were not atheists, but who had turned away from the church for political reasons. The term was considered a sign of a special ideological closeness to National Socialism. In 1944, Wannemacher was appointed to the "Beirat des Bevollmächtigten für das Gesundheitswesen Karl Brandt" (Advisory Board of Karl Brandt, Plenipotentiary for Health Care) – Karl Brandt was the most

senior Nazi physician in the Third Reich and the appointment also represented a political vote of confidence. In his much-cited encyclopaedia of persons in the Third Reich ("Das Personenlexikon zum Dritten Reich"), Ernst Klee counted Wannemacher among the "leading dentists of the Nazi era", probably against the background of his various Nazi-specific functions and offices [56].

Wannemacher acted as Harndt's mentor in Berlin and accompanied his habilitation project, which was extremely successful: Harndt was admitted to the habilitation in 1936 and was able to complete the procedure without difficulty. Shortly thereafter he was awarded the prestigious Miller Prize by the DGZMK – explicitly for his habilitation study.

Both successes are also particularly noteworthy because after 1945 Harndt stated in the archival documented denazification proceedings that he had suffered disadvantages in the Third Reich "because of political unreliability" [60]. As central evidence of this, he stated in a document entitled "Annex 2" that he was not appointed as a lecturer until 1939 (Fig. 3, [60]). He also claimed in a "Berufungsregistrierungsformular" (appointment registration form) that his entry into the NSDAP had been forced ("unter Zwang") [60]. On the official "Fragebogen" (Questionnaire) of the military government, he further noticed (1) that he had only been a party candidate ("Anwärter"), not a member, (2) that he applied for admission to the party in 1938, (3) that he had left the NSDAP in 1941 and (4) that no party number had been assigned to him (Fig. 4, [60]).

To start with the information provided in the questionnaire: none of the four allegations was really correct; according to the sources consulted, he was not merely a candidate but a member of the party (Fig. 5, [12, 60]). Nor had he applied for membership in 1938, but had already joined the party in 1937. Besides, it would not have been possible earlier: It was not until early summer 1937 that the membership ban imposed in May 1933 to prevent political opportunists from joining the party was relaxed. Harndt actually submitted the

application on July 27, 1937 and was admitted retroactively as of May 1, 1937 – the earliest possible date [12]. This chronological sequence – namely the prompt backdating carried out by the party – also shows that his admission to the party apparently took place without reservations. However, precisely this would have been to be expected from a politically unreliable applicant. The sources also repeatedly document that Harndt – contrary to his assertion – indeed was given a party number: It was 4,360,633 (Fig. 5). The statement that he had resigned from the party in 1941 was also incorrect. Harndt tried to “save” it by means of a later explanation which stated that he had not paid membership fees since 1941 (“In 1941 I stopped paying my membership fees”) – which, if true, was quite different from declaring one’s withdrawal from the party. In the NSDAP membership file there is indeed no mention of a party resignation – neither for the year 1941 nor for a later date [12]. In other words: By means of four incorrect statements Harndt tried to reinterpret an 8-year party membership (1937–1945) into a 3-year candidacy (1938–1941).

It is true that Harndt’s appointment as a Privatdozent was made with a noticeable delay. However, here too, he came up with half-truths: In fact, it was not a period of “more than 3 years” as Harndt claimed in the denazification proceedings (Fig. 3, [60]), but less than two years: The habilitation was awarded on June 10, 1936 with the conferral of the Dr. med. habil., the appointment as Privatdozent on April 19, 1938 – Harndt himself provided this information about his person *before* 1945 in writing in a file card [2].

Moreover, the reasons for the delayed appointment were far less serious and far less fundamental than Harndt later insinuated: Harndt was by no means *per se* considered politically unreliable or suspect. The Nazi system had a polycratic structure, i.e. it was characterized by a multitude of responsible, often competitive persons and centres of power. This polycracy was also evident in the Harndt case: As usual, various statements were obtained before appointment as

a Privatdozent. Some very positive assessments of Harndt were joined by criticism from the student and lecturer leadership, according to which Harndt (1) showed a “certain flippancy” “towards students and patients”, which would not correspond to the (supposedly high) demands made on a university teacher in the Third Reich, and (2) that he had a “well-functioning private practice”, which would or should not be allowed to assistants and why he should not be appointed as Privatdozent [3]. However, these 2 arguments were contradicted in several other statements – among others by Eugen Wannemacher himself, who emphasised that Harndt had “proven himself perfectly”. Earlier, Professor Hermann Schröder had already pointed out that Harndt was “politically absolutely reliable”. It was also stressed that the admissibility of a private practice in question was irrelevant to the assessment of Harndt’s personal suitability [3].

Such disparate statements in matters of promotion or appointment were the order of the day in the Nazi polycracy – as well as internal party power struggles and personal profiling attempts at the expense of others. Prominent cases from the field of dentistry include professors such as Guido Fischer [25] or Friedrich Proell [18] or the dentist Friedrich Krohn [67], all of whom were convinced National Socialists, but became involved in internal party disputes and were discredited – nevertheless, they were no political opponents, but representatives of Nazi ideology. In most cases, such differences of opinion ultimately had no consequences – as in the case of Harndt: from 1936 onwards, he passed through a whole series of career stages that would not have been possible for politically suspicious persons. Not only was he admitted to the habilitation procedure, as mentioned above, and chosen as a Miller Prize winner by the politically centralized professional society (1936 respectively 1937), but he was also accepted as a member of the NSDAP (1937) and subsequently – albeit belatedly – appointed as a Privatdozent (1938). In the following year, he was

promoted to (better paid) “Dozent der neuen Ordnung” and in 1944 to titular professor. A short time later, due to an illness of Wannemacher, he was appointed provisional head of the department [66].

Remarkably, a curriculum vitae written by Harndt himself around 1944 is documented, in which no mention is made of the later claimed “political unpopularity” or discrimination. Rather, it states succinctly: “In May 1936, the medical faculty of the Berlin University pronounced my habilitation. In 1937 I attended the Lecturers’ Academy in Kiel-Kietzeberg for 3 weeks, whereupon I was appointed lecturer in dentistry on 19.4.1938” [3]. He thus documented with his own hand that there were not more than 3 but less than 2 years between the habilitation and the appointment as Privatdozent.

On an undated questionnaire from around 1938, Harndt was asked about a possible “political activity”. He did not negate the question, but noted the following activities: “Sturmarzt i. NSKK, Arzt i. Hauptamt f. Volksgesundheit, NSDAP” (Storm doctor at NSKK, doctor at the General Office of Public Health, NSDAP) [3].

Harndt did not take too much care with other statements in the denazification proceedings either: While he stated in 1946 that he had only entered into a NSDAP candidacy and an NSKK supporting membership, he revised this statement one year later in an addendum that he submitted to the “Denazification Commission” on April 3, 1947 (Fig. 6, [60]): He now declared that he might also have “got into” the membership lists of the NS Medical Association (NS-Ärztebund) and the NS Lecturers’ Association (NS-Dozentenbund). In the first case, he argued that there might have been an automatic inclusion in the course of the political centralization, in the second case, he conceded that he “possibly responded to a request” [to become a member]. In both cases, however, he stated that he was not quite sure [12, 60].

These “gaps in memory” are not plausible for the simple reason that Harndt himself filled out a university teachers’ card in the Third Reich, in

Frenzel, A. (Berlin): Die Kariesbereitschaft beim kindlichen Schwachsinn. Dtsch. Zahn-Mund-Kieferhbk. 3, H. 7, 493 (1936).

Um festzustellen, welchen Anteil die sogenannten Hilfsschüler, also die geistig-seelisch minderwertigen Kinder an der prophylaktischen Fürsorge durch die Schulzahnpflege nehmen, wird die Kariesbereitschaft beim kindlichen Schwachsinn geprüft. Nachdem zunächst das diagnostische Bild des erbkranken Schulkindes beschrieben ist, bringt die Arbeit sozial-statistische Zahlen über die Kariesanfälligkeit von etwa hundert biologisch minderwertigen Hilfsschülern. Bei annähernd gleichem Zahnbestand wie bei den normalsinnigen Kindern zeigten die schwachsinnigen deutlich eine niedrigere Kariesfrequenz. Verf. untersuchte nun, ob die für die Bezahnung des Hilfsschülers gefundene auffallend verminderte Kariesanfälligkeit sich etwa von einer Immunität gegenüber Fäulnisprozessen in der Mundhöhle ableiten läßt und kommt zu dem Ergebnis, daß der allgemein körperliche Gesundheitszustand, mit dem die vererbt geistig minderwertigen Kinder oftmals ausgestattet sind, auch seinen Ausdruck in einem kraftvoll entwickelten Kauorgan mit lückenlosen Zahnreihen findet. E. Harndt (Berlin)

Figure 7 Harndt's review of the publication by A. Frenzel (1937)

which he gave complete details in the pre-printed column "Membership in national associations". There he listed: "NSDAP, NSKK, N.S. Ärztebund, N.S. Dozentenbund, Hauptamt für Öffentliche Gesundheit, Luftschutzbund" [2].

The half-truths, corrections and dramatizations mentioned above fundamentally undermine the credibility of Harndt's statements in the denazification proceedings. The latter also applies to his notice that his application for admission to the NSDAP had been "forced" [60]. The membership ban imposed from 1933 to 1937 rather points to the opposite: the party wanted to protect itself especially against members who did not join out of inner conviction. In fact, there are several examples of applications for membership that were rejected because the candidates were considered politically suspect, such as the dentist Hans Hermann Rebel, director of the Dental Institute of the University of Göttingen since 1925 [7], or Ferdinand Lehm, who was at times chairman of the Prussian Dental Association and was to become head of the social welfare organization of the "Verband der Deutschen Zahnärztlichen Berufsvertretungen" (Association of German Dental Professional Associations) in 1952 [6]. It is very likely, however, that Harndt was advised to apply for

membership in view of his intended university career or that he himself realized that membership could be helpful. There is no doubt that in many cases, party membership favored careers. It is not without reason that around 60 % of dental lecturers became NSDAP members in the Third Reich – but that also meant that 4 out of 10 university lecturers did *not* join the party [32]. Besides, the latter group also included representatives who were well-esteemed in the Third Reich, such as the professors Otto Loos [28] and Paul Adloff [52] or the up-and-coming lecturers Karl Schuchardt and Richard Trauner. Concerning Trauner, no less than 4 expert opinions by leading professors of the Third Reich are documented, who gave him a positive report around 1943/44 – despite his lack of party membership – and assessed him as suitable for a chair [8].

In addition, there are other facts that were not even mentioned in Harndt's denazification proceedings, but which raise all the more doubts about Harndt's self-staging as a politically unpopular, disadvantaged lecturer: During the Third Reich Harndt repeatedly reviewed publications devoted to Nazi ideology and especially to eugenics and so-called hereditary diseases. In the "Zentralblatt für die gesamte Zahn-, Mund- und Kieferheilkunde" (Central Gazette for all

Dental, Oral and Maxillofacial Medicine) alone there are 10 reviews by Harndt – "mainly from the category of eugenics" [73]. Why Harndt found himself willing to review such delicate writings at all, and thus to take a political position, is not evident from the files. What is certain, however, is that he did not in the least distance himself from the research approach or content of the reviewed works. It is also conspicuous that he made completely uncritical use of NS terminology. An example is Harndt's review of A. Frenzel's publication on the caries incidence in "infantile idiocy" (Die Kariesbereitschaft beim kindlichen Schwachsinn) [19]. Harndt writes about this literally (Fig. 7, [39]): "After first describing the diagnostic picture of the hereditary sick school child, the work brings social-statistical figures about the caries susceptibility of about one hundred biologically inferior children (*biologisch minderwertigen Hilfsschülern*)." He also uses the Nazi phrases "geistig-seelisch minderwertige Kinder" and "vererbt geistig minderwertige Kinder" [39].

A second example is the review of a contribution by H. Eckhardt on the possible forced sterilization of patients with cleft lip and palate ([15]. Harndt wrote his review in 1940, by which time leading professors such as Georg Axhausen, Wolfgang Rosenthal and Franz Ernst had long since

Eckhardt, H. (Berlin): Die Beurteilung der Lippen-Kiefer-Gaumenspalten im Hinblick auf das Gesetz zur Verhütung erbkranken Nachwuchses. Dtsch. Zahn-Mund-Kieferhkl. 5, H. 4, 260 (1938).

Es wird untersucht, ob die Lippen-Kiefer-Gaumenspalten als „schwere erbliche körperliche Mißbildungen“ im Sinne der Ziffer 8 des § 1 des Gesetzes zur Verhütung erbkranken Nachwuchses angesehen werden können. Obwohl die Spaltbildungen Hemmungsmißbildungen aus dem zweiten Fötalmonat und damit als „körperliche Mißbildungen“ anzusehen sind, so sind doch nur die Gaumenspalten und der Wolfsrachen als „schwere“ Mißbildungen zu betrachten. Diese Spaltbildungen können aber heute durch operative und prothetische Methoden in leichte Mißbildungen umgewandelt werden. Die Unfruchtbarmachung bei diesen Erkrankungen wird daher abhängen von dem jeweiligen Nachweis der Erbllichkeit, das heißt dem wiederholten Vorkommen der Mißbildung in schwerer, leichter oder leichtester Form innerhalb der Blutsverwandtschaft.

E. Harndt (Berlin)

Figure 8 Harndt's review of the publication by H. Eckhardt (1940)

revealed a protective attitude towards their “cleft patients” and criticized forced sterilization as the wrong approach, while Martin Waßmund and Reinhold Ritter, for example, took opposing positions [24, 26, 30, 33, 72]. Harndt could therefore have simply referred to the arguments of Axhausen et al. In Harndt's review, however, there is nothing to be found of that criticism or of the entire professional dispute about forced sterilization. He refers to the content of the publication without questioning the approach. Finally, he sums up uncritically (Fig. 8, [40]): “Sterilization (*Unfruchtbarmachung*) for these diseases will therefore depend on the respective proof of heredity, i.e. the repeated occurrence of malformation (*Mißbildung*) in severe, mild or mildest form within the consanguinity (*Blutsverwandtschaft*)” [40].

Harndt's recourse to typical NS terms (“*vererbt geistig minderwertige Kinder*”, “*Unfruchtbarmachung*”, “*Mißbildung*”, “*Blutsverwandtschaft*”) is not only found in his reviews. On an undated questionnaire from around 1938, for example, Harndt described himself as “*deutschreligiös*” – this is, similar to the word “*gottgläubig*”, a typical Nazi term to express the distance to the churches and the proximity to the (church-critical) Nazi ideology [2].

Even for the last years of the Third Reich, the available sources do not reveal any evidence that Harndt was in a political outsider role. On the contrary: In the years 1943/44,

Harndt was evaluated by 3 dental university lecturers with regard to his ordinability – his suitability for appointment to a chair: Erwin Reichenbach, Otto Hofer and Eugen Wannenmacher, all of them loyal NSDAP members, unanimously classified him as suitable [5]. Obviously Harndt continued to have the support of influential dental professors. This explains why, as mentioned above, he was appointed a titular professor in 1944 and shortly afterwards as the provisional head of the department.

After 1945: Public perception and reception of Harndt's role in the Third Reich

As mentioned, after 1945 Harndt tried to emphasize his distance to the Nazi system, his political unreliability and his political discrimination. As was customary in denazification proceedings, he provided several character references that outlined him as anti-national socialist and as pro-Jewish and confirmed that he was considered politically suspect and therefore had been disadvantaged. Affidavits of that kind can be found in countless denazification proceedings. Such “*Persil Certificates*” ultimately had the effect that the overwhelming majority of the defendants were able to conclude their proceedings more or less unscathed [55]. This course of events was particularly pronounced in Bavaria. This was also due to the person of George S. Patton, who was the first American military governor after the end of the war and was con-

sidered anti-Semitic and politically permissive [65]. At this point, it should not go unmentioned that the “*denazification procedures*” were handled very differently in the 4 occupation zones. Overall, the hardest action was in the “*Soviet-occupied zone*” (SBZ), the later GDR including West Berlin: Here thousands were imprisoned (partly in former concentration camps) or sent to labour camps. However, the procedure in the SBZ was also the most inconsistent and least transparent: Often it was not only the entanglement in the Nazi era that decided the verdicts, but also factors such as “*class affiliation*” or the potential benefit of the person under review for the planned “*construction of socialism*”. In fact, denazification ended mostly as a “*farce*” in the West and as “*self-congratulation*” in the East [23, 65].

Harndt's Hamburg colleague Heinrich Fabian – an extraordinary Professor and a fervent National Socialist – provides an impressive case for such developments: At that time Hamburg was located in the British occupation zone, where politically inactive party members were sometimes exempted from punishment at an early stage. In 1949, the first Impunity Act also brought an amnesty for most of those previously sentenced by the denazification authorities. Fabian also profited from this development: After the war, the responsible denazification committee of the Hamburg University had initially assessed him as “*no longer acceptable*”

as a doctor, which meant he was banned from his profession. One year later, the responsible authorities at least allowed him to work in a medical practice, while he was still banned from teaching. However, Fabian was not yet satisfied and reacted with requests for revision (appeals), which aimed at further rehabilitation. His persistence brought the desired success: while one appeal in May 1948 still failed, another one was accepted in May 1949. The new examination now suddenly revealed that Fabian had “put up strong resistance” to the Nazi regime. It was therefore decided in the end to “classify him in category V with the lifting of all professional restrictions”. Thus Fabian was considered to be completely “exonerated” and was able to continue his work as a professor [29].

Thanks to the system of “Persil Certificates”, even ardent National Socialists overcame the supposed hurdles of denazification, and the ruling chambers became true “follower factories” (Mitläuferfabriken) [65] at the latest in the appeal proceedings. Even blatant Nazi perpetrators such as Hugo Blaschke, SS General and Hitler’s personal dentist, or Karl Pieper, “Reichsdozentenführer” (Leader of the Reich Lecturers) of the dental profession and holder of the Blood Order, were denazified as mere “followers”. The same applies to Paul Reutter, who, as “leading dentist”, was responsible for all dental matters in the concentration camps until 1943 [23]. In the end, only about 1.4 % of those affected in the denazification proceedings were classified as (significantly) burdened [65].

Harndt, too, took this hurdle unscathed: Although his denazification dragged on until January 1948, it ended with the discontinuation of the proceedings [60]. Harndt’s dictum in the denazification proceedings that he had been politically suspect to those in power in the Third Reich and had therefore suffered repression, proved to be extremely persistent. For example, Erwin Reichenbach – also a former party and SA member [69] – noted in a laudation on the occasion of Harndt’s 60th birthday (1961) that the latter had to wait longer than usual for his lecture-

ship: “‘Political unreliability’ had caused this delay” [66].

This assertion was hardly questioned, on the contrary. How powerful this dictum was became apparent in 1991 – i.e. another 30 years later – on the occasion of Harndt’s 90th birthday. Here it was said with regard to Harndt’s party membership: “We know [...] that making compromises with the politically powerful is a question of existence” [64]. In the same context, Harndt was described as a political suspect and thus brought close to being a Nazi victim. There it was said in abbreviation of the real facts: “Clear expressions of mistrust also affected the then senior assistant Harndt [...] a teacher who was not welcome in the NS state” [64]. A similar comment can be found for 1993 [62].

In contrast, Künzel offered a more realistic commentary: In 2018 he criticized the attempts of the aforementioned authors to ascribe a political “victim role” to Harndt. Künzel calls the aforementioned “expressions of mistrust”, which Harndt had experienced in 1936 after his habilitation, merely “a temporary mishap which he was able to clear up shortly afterwards by joining the NSDAP” [59] – an overall assessment that is much better in line with the sources.

Conclusions

Harndt was certainly not a “fervent”, ideologically convinced National Socialist. Unlike his mentor Wannemacher, he did not seek political offices and functions. But he did not distance himself from the Nazi regime, he was by no means – apart from individual voices – perceived as politically unreliable or suspect. Therefore, it does not seem justified to place him in the vicinity of Nazi victims. Such a reading would do injustice to those who actually became victims: by being dismissed from university service, prevented from completing their habilitation, excluded from professional networks, driven into emigration or fearing for their lives. Such professors and lecturers also existed in dentistry at many universities – Alfred Kantorowicz [27] and Hans Moral [22] are certainly the most prominent examples. But they

were also to be found in Harndt’s immediate professional environment: Konrad Cohn, Konrad Lipschütz [57] and Hans-Jacques Mamlok [61] were Berlin colleagues – they *did* fell out of favour with the National Socialists and lost their professional and ultimately their life perspective.

Harndt is neither a Nazi perpetrator nor a victim. Rather, he shows the characteristics of a classic follower: He made use of the professional networks – which, in addition to Wannemacher, also included experts such as Hofer and Reichenbach – and he served the Nazi system by joining Nazi organizations, by agreeing to write uncritical reviews of morally questionable writings propagating Nazi eugenics, and by using Nazi terminology in various contexts. Nevertheless, after 1945, he succeeded in embellishing his role in the Third Reich – not least by stating numerous half-truths and by deliberate omissions. He thus achieved a far-reaching political “cleansing”, which in turn sustainably facilitated his impressive post-war career.

However, not only Harndt, but also his former mentor Eugen Wannemacher found his way back to success in post-war Germany. Like Harndt, he was first dismissed from service by the Allies in 1945 – at that time in the position of an extraordinary professor. Wannemacher initially had to set up his own practice. However, the time factor was also helpful here: In 1955 the University of Münster appointed him full professor of dental, oral and maxillofacial surgery and director of the university clinic of the same name – which meant that Wannemacher ultimately succeeded in further developing his career compared to the Nazi era. [51]. In 1971 he even became an honorary member of the DGZMK – exactly 4 years after his former protégé Ewald Harndt [31].

Conflicts of interest

The author declares that there is no conflict of interest within the meaning of the guidelines of the International Committee of Medical Journal Editors.

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(Photo: University Hospital Aachen)

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Biofilms on polymeric materials for the fabrication of removable dentures

Introduction: Oral microorganisms can contribute to the pathogenesis of many diseases in the oral cavity such as caries, periodontitis, peri-implantitis and denture-related stomatitis. Yet, oral microorganisms may also have a considerable influence on the onset of systemic medical conditions such as lung or cardiovascular diseases. Microorganisms are organized in biofilms and they colonize teeth, mucosa, and dental restorations; the extent to which biofilms are accessible during self-performed oral hygiene varies widely.

Discussion: The current demographic trends show that the population is getting older and that an increasing number of elderly and multimorbid patients require nursing care, most of whom already have and/or will receive removable dentures in the future. Impaired motor skills and cognitive abilities often lead to difficulties in self-performed oral hygiene, thus making these patients reliant on others for assistance. The regular accumulation of biofilm on removable dentures, which is not sufficiently removed, may trigger and foster the onset of oral and systemic diseases in immunologically compromised patients. Usually, removable dentures are fabricated from polymeric materials and polymethylmethacrylate is the most frequently used material. In spite of this, many new materials are currently being introduced on the market which can be used to make removable dentures. The range of available materials has become increasingly broad and it includes materials based on polymethylmethacrylate as well as composite-based materials and polymeric materials with a distinct polymer chemistry. Relevant differences exist between the bioadhesion of materials that are processed using classical methods as compared to CAD/CAM-manufacturing.

Conclusion: In this context, the current article aims to describe the importance of biofilms on removable dentures, to outline relevant interactions of oral microorganisms with the surface of polymeric materials, and to present strategies for minimizing bioadhesion on removable dentures.

Keywords: polymeric materials; removable dentures; microorganisms; biofilms; CAD/CAM-manufacturing

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1. The etiology and pathogenesis of biofilm-associated diseases in patients with removable dentures

1.1 The importance of removable dentures

Over the past few decades, both dental care and oral health awareness have notably improved in Germany so that an increasing number of people still have their natural teeth, even at an advanced age [47]. To illustrate this, the number of edentulous patients have halved over the last 20 years; while in 1997 about 25 % of younger seniors between the ages of 65 and 74 years were edentulous, only about 12 % are edentulous nowadays [47]. Nevertheless, almost half of the younger seniors (46 %) wear removable dentures, which underlines their lasting importance in dentistry. For older seniors falling into the age group between 75 to 100 years, and who are also in need of nursing care, the proportion of denture wearers increases up to 86 % [47]. Removable dentures cover large areas of mucous membrane, and thus, provide an extended attachment surface with optimal living conditions for microorganisms; this favors their growth and proliferation together with biofilm formation. Just like for teeth, biofilms that adhere to dentures should be regularly removed. Yet, for older patients in need of nursing care, this is especially difficult to accomplish due to their often limited motor and cognitive abilities (see Fig. 1 and 2).

Nearly 30 % of older seniors receiving nursing care claim that they depend on extra assistance for denture and oral hygiene [47]; this emphasizes the importance of instructing nursing care personnel as well as any other caregivers [93]. Regardless of this fact, the time that caregivers have to help seniors with their daily oral and denture hygiene is limited for a number of reasons [23, 48, 78, 79, 107]. One such motive is that nursing staff have high general care workloads, which means that they have very short time frames for assisting patients with oral hygiene. Secondly, it appears that nurses have deficits with regard to dental training, which leads to difficulties in the recognition, insertion, removal, and cleaning of dentures. Studies have also revealed that care receivers' refusal to accept help with oral hygiene is a further problem, as is the fear of contact on the part of the caregiver [7]. In spite of these background challenges, the mechanical cleaning of removable dentures is still the gold standard, as the simple application of chemical cleaners is not always sufficient, and should therefore be viewed as a supportive measure, particularly with regard to the removal of microorganisms [32].

1.2 Materials used to produce removable dentures

For the fabrication of removable dentures, materials are differentiated based on whether they are processed into rigid or flexible dentures. Various polymer systems for the fabrication of removable dentures are

available on the market, which can be grouped according to the method of processing [90] (see Table 1). The first group consists of materials that can be cured with the help of pressure, heat (special form: microwaves) or light. A second group of materials includes thermoplastic materials, which do not require curing, but are formed by using heat before they solidify. The third group includes industrially cured or thermoplastically processed materials that are subsequently available as CAD/CAM blocks, from which, dental restorations and dentures can be milled.

Polymethylmethacrylate (PMMA) represents the most important self and warm curing resin. It is the most commonly used denture material in everyday practice. PMMA is appealing due to its low cost as well as its ease of reparation and handling [80]. However, the high rigidity of the material has disadvantages such as increased fracture susceptibility and reduced wearing comfort.

Urethane dimethacrylates belong to the group of light-curing resins that are kneadable during processing before their subsequent curing in special ovens with the aid of light. In the fabrication of partial and complete dentures, this processing technique spares the wax-up step [90]. Other applications of light-curing resins include the manufacturing of individual trays, denture relining or orthodontic appliances. In the finished state, they show increased strength compared to warm curing resins [17], but are more brittle and difficult to repair [92].



Figures 1 and 2 Maxillary and mandibular dentures with extensive biofilm deposits and discoloration due to poor denture hygiene belonging to two patients (91 and 77 years old) in need of care

Curable resins		Thermoplastic polymers	CAD/CAM-polymers
Warm or cold curing resins	Light-curing resins		
Polymethyl methacrylate (PMMA)	Urethane dimethacrylate (UDMA)	Polyamides (Nylon)	Polymethyl methacrylate (PMMA)
		Thermoplastic PMMA	Polyaryletherketone (PAEK)
		Polyoxymethylene (POM)	
		Polyaryletherketone (PAEK)	

Table 1 Overview of different processing forms of polymer materials with examples

The group of thermoplastics represents plastic materials which are shaped by the application of heat during the manufacturing of removable dentures, and which have flexible properties after cooling. Due to the elimination of the curing process, neither bite lock nor the presence of residual monomers occur [90]. This material group is thus the favored one for use in patients with methyl methacrylate allergies. Important thermoplastic materials are polyamide-based plastics, for example, which can be used to manufacture flexible dentures. These have the advantage of being easier to fit in the mouth in patients with limited mouth opening (Microstomia). Moreover, they have minimal fracture susceptibility due to their high elasticity [90]. In addition, these materials also have esthetic advantages, as gingiva-colored clasp components can be produced from the material. Disadvantages of polyamides are their limited capacity to be repaired and polished [92]. Moreover, due to their elasticity, there is discussion regarding unfavorable pressure distribution, which can result in increased atrophy of the alveolar ridge [11]. Industrially cured thermoplastic PMMA materials can also be classified in the group of thermoplastics. Yet, in contrast to their counterparts, which are manufactured using the conservative process, they have a lower residual monomer content, but at the same time, also a reduced repair capacity.

Another member of thermoplastic materials is polyoxymethylene (POM) which can be used to produce tooth-colored denture frameworks and clasps. Due to the possibility of designing POM frameworks in gingiva color, the fabrication of complete denture bases from POM is conceivable. However, this material cannot be extended and it requires greater spatial dimensions compared to metal clasps and frameworks [92].

Newer processing methods that employ CAD/CAM-manufacturing enable the milling of denture bases, complete dentures and denture frameworks from industrially prefabricated blocks. Industrially pre-cured PMMA is suitable for the production of denture bases or complete dentures. The absence of polymerization shrinkage and a low residual monomer content are significant advantages compared to conservatively processed PMMA. Moreover, the more homogeneous and pore-free nature of CAD/CAM materials appears to have a positive influence on their mechanical properties [90, 97]. The polyaryletherketones (PAEK) are suitable, stable alternative framework materials that are used in the CAD/CAM-manufacturing of denture frameworks for complex removable dentures for patients with allergies against metals [33]. PAEKs belong to the family of high-performance thermoplastics, which were introduced to the dental market in 2006 [90, 94]; prior to that, they were used

during spinal surgery for instance. PAEK materials have improved mechanical properties [73, 97], low weight [33] and a low interaction with biological materials, which contributes to their low allergenic potential [113]. However, the capacity to repair or extend PAEKs is low and they scratch faster than PMMA [41]. Furthermore, to date, there is hardly any clinical data on the long-term performance of these materials in an oral cavity. Regardless of the material, CAD/CAM-manufacturing allows the easy reproducibility of dentures in case of loss or damage thanks to the stored CAD/CAM data. Also, denture modifications such as relining can be made digitally and the dentures can then be manufactured again [90].

Since the supporting alveolar bone for a denture changes in the course of the wearing period, relining to improve mastication and reduce pressure points may be indicated. For this purpose, a distinction is made between rigid relining materials such as cold curing PMMA and soft relining materials based on silicone or acrylate [52, 85]. The latter group of materials is mainly used for removable denture relining in cases of unfavorable morphology of the alveolar process; examples include strongly undermined alveolar ridges, flabby ridges or strongly atrophied alveolar ridges with an exposed inferior alveolar nerve [16]. Moreover, these materials are indicated in situations that require minimal load on the

denture supporting tissues such as after surgical interventions (e.g. extractions or implant insertion).

1.3 Biofilm formation

The oral cavity provides habitat for a variety of microorganisms, with bacteria and fungi being the main colonizers of teeth, mucous membranes and dentures (see Fig. 3). Over 700 different types of bacteria have been identified as components of the oral microbiome [50]. Before bacteria or fungi attach themselves to teeth or dental restorations and form biofilms, a so-called acquired pellicle develops on all natural surfaces of the oral cavity and on the surface of dental restorations within seconds to minutes after cleaning [37, 46, 104]. The pellicle consists mainly of proteins (including enzymes), carbohydrates and lipids derived from saliva, gingival sulcus fluid or bacteria [38]. Their formation is initially based on electrostatic interactions. The phosphate ions contained in saliva contribute to the negative charge of teeth and dentures; the positively charged calcium ions, which are also present in saliva, are therefore attracted via electrostatic forces and embed proteins (e.g. phosphoproteins, statorin, histatin) in between the ion layers. Additionally, Van der Waals forces and protein-specific charged functional groups increase the adhesion of the initial pellicle to the surface of teeth and dentures [105, 106]. Furthermore, the subsequent coupling of protein aggregates from saliva via protein-protein interactions with the already immobilized proteins of the initial pellicle follows.

Pellicles display different ultrastructures and thicknesses depending on their location, with these being mostly determined by the salivary biopolymers present at the respective location and the existing shear forces, but less by material-related parameters [36]. However, the material itself influences the composition of the pellicles. For example, fewer statherines and histatines, which are responsible for defense, are found on denture materials [22]. At the same time, the pellicle can hide the properties of the underlying substrate [28, 35]. Other than serving to lubricate and protect

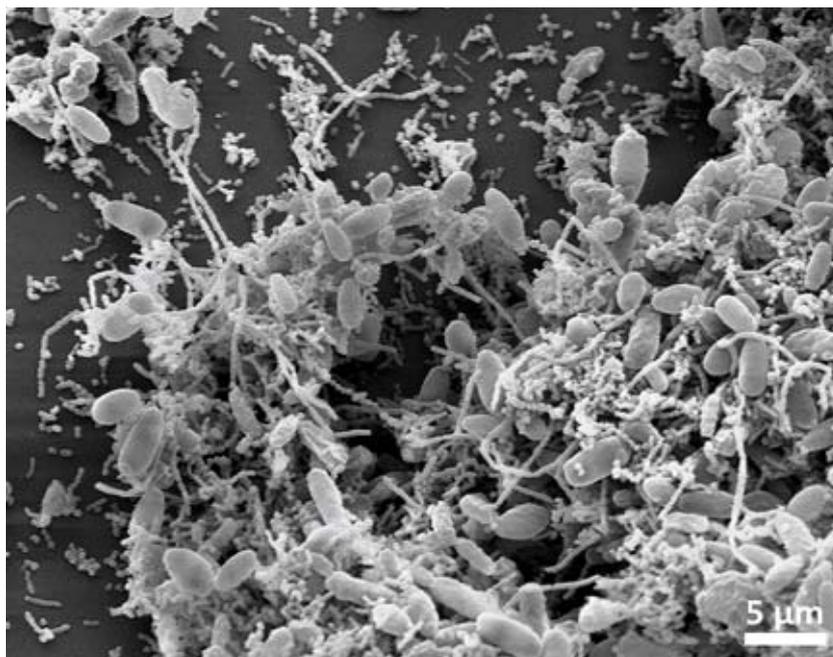


Figure 3 Scanning electron microscope image of an oral multi-species biofilm from the plaque of a patient suffering from periodontitis after 72 hours of anaerobic in-vitro cultivation on glass

(Fig. 1, 2 and Tab. 1: E. Günther, Fig. 3: N. Kommerlein)

tooth surfaces, pellicles play an equally important role for microbial attachment to teeth and removable dentures. Components of the pellicle serve as receptors for the attachment of microorganisms. Initially, mainly Gram-positive streptococci (e.g. *Streptococcus oralis*, *Streptococcus sanguinis*, *Streptococcus mitis*) and rods (e.g. *Actinomyces naeslundii* or *oris*) colonize the pellicle, thus making them among the early colonizers. As the bacterial biofilm matures, further microorganisms are integrated into the biofilm over a period of days. Gram-negative cocci (e.g. *Veillonella* spp.) attach themselves to the early colonizers at first. Then, they are followed by Gram-negative, filamentous species such as the bridge germ *Fusobacterium nucleatum* and late colonizers (e.g. *Capnocytophaga sputigena*, *Porphyromonas gingivalis*, *Aggregatibacter actinomycetemcomitans*, *Treponema denticola*, *Tannerella forsythia*, *Prevotella intermedia*), some of which are leading germs of oral infections [54, 61, 62]. Fungi such as *Candida albicans* can also interact with bacteria such as *Streptococcus gordonii*, *S. oralis*, *S. sanguinis* [57, 81], *A. oris* [31] and *F. nucleatum* [30] and take part in the complex oral biofilm

community [112]. Yet, the presence of specific pathogens alone is not sufficient for the development of diseases in the oral cavity. Instead, the dynamic interactions between the microorganisms and the host organism, particularly the host's immune defense, play a decisive role in the development of biofilm-associated diseases. Diseases that can be caused by oral microorganisms include both local manifestations as well as systemic diseases.

1.4 Local diseases caused by biofilms in denture wearers

The fungus *C. albicans* is of particular importance in this context, as it plays an essential role in the development of denture-related stomatitis [10]. Wearers of complete dentures are more likely to develop denture-related stomatitis than wearers of partial dentures [1], which is most likely resulting from the larger interface. Denture-related stomatitis has a prevalence of up to 75 % [27]; it manifests itself as local redness of the mucosa that is covered by the denture and is often accompanied by burning, discomfort, impaired taste or pain. The development of denture-related stomatitis is dependent on

several favoring factors. Inadequate oral and denture hygiene, wearing of the denture all day with the associated reduction in the pH value of the oral mucosa to below 6.5, as well as a weakened immune system can promote the manifestation of *C. albicans* [27, 63]. In this way, the virulence of *C. albicans* appears to grow with increasing biofilm maturation, as the fungus undergoes a morphological transformation from predominantly blastospores to hyphae [98]. Studies have revealed that the material surface can also trigger the transformation of blastospores into hyphae [16, 20, 87]. The latter microorganisms are able to invade the affected mucous membrane areas with the help of enzymes and penetrate deeper into mucous membrane layers [10, 59, 98]. Aspartate proteinases, in particular, appear to accelerate the degradation of host proteins and thus promote the invasion of *C. albicans* [42]. Studies have proven that the activity of proteinases correlates with the severity of denture-related stomatitis [89]. Moreover, *C. albicans* which were organized in biofilms showed higher aspartate proteinase secretion levels than planktonic *C. albicans* [68]. This fungus, like other microorganisms, can also degrade material surfaces, which leads to material roughening and the further irritation of the mucosa [87].

1.5 Systemic diseases triggered by biofilms in denture wearers

In recent years, numerous studies have shown that microorganisms in the oral cavity can substantially influence and promote the development of systemic diseases. Oral infections such as periodontitis lead to cell aging (senescence): in comparison to healthy patients, the telomerase activity of affected patients is increased and cannot be reduced, or only slightly reduced, by protective measures such as exercise [67]. Other studies have identified oropharyngeal bacteria in atherosclerotic plaques [5, 21, 69], which suggests that bacteria can enter the bloodstream via the periodontal support apparatus, and thus, promote the development of cardiovascular diseases. With regard to

the importance of biofilms on removable dentures, respiratory pathogens have been detected in biofilms on dentures [82, 103], which confirms an association between the occurrence of pneumonia and the wearing of removable dentures [23, 43]. The presence of respiratory pathogens in biofilms on teeth and dentures seems to be related to the pathogenesis of nosocomial pneumonia, but also to the initiation or progression of chronic obstructive pulmonary disease [91]. Pneumonia is one of the most common diseases in the elderly population and, with a mortality rate of 25 %, is one of the most frequent causes of death [76, 95]. In particular, swallowing disorders (dysphagia), wearing dentures at night, inadequate denture hygiene and a weakened immune system favor the development of aspiration pneumonia [71, 91]. Besides aspiration pneumonia, gastrointestinal infections belong to possible disseminated infections caused by the accumulation of oropharyngeal bacteria on denture surfaces [77].

Various studies have shown that improved oral hygiene, with the accompanying lower germ load, has a positive effect on morbidity and mortality from pneumonia: In this manner, 10 % of pneumonia-related deaths in nursing homes could be prevented by improved oral hygiene [95]. Optimized oral hygiene also seems to be more effective in reducing pneumonia-related mortality rates than drug therapy. Besides this, patients with improved oral and denture care experienced a shorter fever duration than patients who did not intensify oral and denture hygiene [109].

2. Modern materials and strategies for modulating biofilm formation and removal from removable dentures

In the development of new dental materials, the optimization of mechanical properties such as flexural strength, resistance to fracture or hardness and the improvement of the esthetic appearance are often the major focus. However, the above-mentioned considerations concerning the prevalence and importance of biofilms on removable dentures show

that strategies, which minimize the adhesion of biofilms to removable denture materials, or allow easy removal of these biofilms from the surface of the dentures, could contribute significantly to maintaining the oral and systemic health of denture wearers. For this reason, in addition to optimizing the mechanical and esthetic properties of denture materials, biological considerations should also be taken into account when these materials are further developed.

2.1 Modification of biofilm formation on removable dentures by means of material properties

For the adhesion of biofilms on polymeric materials, it seems that their chemical composition, in particular, as well as their surface roughness, energy and topography are relevant properties. In general, their influence decreases with increasing biofilm thickness [35]; this substantiates the idea that a potentially preventive influence of the material must be maintained by regular mechanical removal of the adhering biofilm. This further implies that innovative material-associated strategies for controlling biofilms on polymeric materials for the production of dentures must have sufficient resistance to withstand the necessary repeated mechanical cleaning.

A high surface roughness generally causes an increased accumulation of microorganisms due to the increased surface area available for adhesion and the furnishing of niches protecting against shear forces, which can in turn be decreased by polishing. Although macrofilled resin composites of earlier generations, especially, were associated with high surface roughness, and thus high plaque accumulation, modern hybrid resin composites show much better behavior in this regard [44]. However, different degrees of biofilm adhesion were observed for different CAD/CAM materials despite comparable surface roughness. The group of polymers showed the lowest biofilm adhesion: Polymer materials such as denture base materials have a larger proportion of organic components, which presum-

ably cause less bioadhesion than inorganic components [4]. To date, there have been very few studies regarding the accumulation of biofilms on modern materials for the CAD/CAM-fabrication of removable dentures. Lower surface roughness values and lower adhesion of *C. albicans* have been demonstrated for PMMA processed by CAD/CAM than for PMMA produced by conventional methods [72]. Hence, it can be assumed that, in addition to improved mechanical properties, biofilm adhesion is also lower for removable dentures fabricated using CAD/CAM technology as compared to conventional fabrication of polymer materials [83, 97].

The chemical composition of polymeric materials also appears to play an important role in the adhesion of microorganisms. The addition of antibacterial substances to dental materials can be one means of delaying or minimizing biofilm adhesion and growth. Possible antibacterial additives include silver ions [15, 108], zinc oxide nanoparticles [101] and chlorhexidine [60]. The best known antibacterial dental material is amalgam. However, the example of amalgam shows that the development of effective antibacterial materials is always a balancing act between antibacterial [9, 40] and cytotoxic effects [64]. Furthermore, the release of antibacterial substances has the disadvantage of having a temporary effect. Substances which are added, or more specifically, their release can have a negative influence on the mechanical properties [2, 51, 110]. It has been shown that with increasing polymerization time of resin composites, and thus with a presumably decreasing concentration of uncured monomers, the adhesion and proliferation of some bacterial strains also decreases [14]. Consequently, not only for mechanical, but also for biological reasons, the careful curing of the corresponding materials by heat, pressure and/or light based on the manufacturer's instructions is strongly recommended. In recent years, the processing and machining of dental materials such as PAEK or PMMA by means of CAD/CAM-processing has become established. Unfortunately, there are

only a few studies investigating biofilm formation on PAEK materials [96]. Some studies have presented a lower bioadhesion on PAEK materials than, for example, on conventionally processed PMMA [35,70]. To date, however, it has not been conclusively clarified which mechanism is responsible for this finding. One assumption is the more homogeneous composition and high curing degree of CAD/CAM vs. conservatively processed materials.

Studies on the effect of the surface topography of dental resin composites on the adhesion of microorganisms show that microstructured surfaces are more hydrophobic due to higher water contact angles, thus resulting in increased air inclusions, which in turn reduces the total available contact area between materials and microorganisms [25]. In addition, the topographic barriers lead to a reduction in Quorum Sensing between the microorganisms [25]. For direct dental restorations, this effect can be exploited by using microstructured matrices for filling placement. With the aim of optimizing polymeric materials for indirect dental restorations, special polishing regimes are conceivable that leave a specially structured surface. Studies have shown that different polishing regimes, which produce diverse surface patterns, tend to have different degrees of bioadhesion, even if they have a comparable final roughness [34, 44, 86]. With regard to denture bases that are not polishable, the fabrication of removable dentures using CAD/CAM-processing could be interesting, since these materials appear to exhibit positive properties with regard to biofilm adhesion [72]. While the surface topography of polymers can be modified by polishing and production methods, biomimetic microstructuring of metals is possible with the aid of special lasers and this has shown reduced microorganism attachment [3, 18]. Thus, the surface structuring of metal denture frameworks using laser offers a prospect for the further development of dental biomaterials.

The effects of different denture materials and their surface properties on bacterial adhesion and biofilm

formation have not yet been sufficiently characterized. However, the elucidation of the underlying mechanisms could make a significant contribution to the future optimization of denture materials from a biological point of view; the aim would be to reduce the prevalence of biofilm-induced diseases in denture wearers in the long term. For both approaches, elucidation of mechanisms and development of innovative denture materials, reproducible model systems close to clinical practice can be used; the oral multi-species biofilm model can, for example, be used for in-vitro studies under static and under dynamic flow conditions that resemble clinical practice [55, 56]. This model is already being used in dental implant research [19]. Such in-vitro analyzes, which are frequently performed by means of high throughput screening, should be complemented, or validated, by in-situ studies, such as by placing test specimens in splints or dentures. In-situ approaches have the advantage of allowing biofilm formation to occur under the natural conditions of the oral cavity.

2.2 Modification of the adhesion of *Candida albicans* on removable dentures through material properties

Since denture bases are usually not polished and the denture plastic can be penetrated by *C. albicans* [66], the rebasing or the new fabrication of the denture is advisable, especially for older dentures and existing denture-related stomatitis, so as to avoid reinfection after antimycotic therapy of the mucous membranes [58]. It is known that *C. albicans* reacts less sensitively to antifungal therapy, particularly in pores of rough material surfaces [102] and leaves endotoxins in these pores, which further sustain the infection by slow release [16]. A reduced attachment of *C. albicans* occurs on smooth and hydrophilic surfaces [29, 75, 88, 100, 111]. Additionally, a relationship between the basic part of the surface free energy and the adhesion of *C. albicans* could be demonstrated [49]. Furthermore, it has been shown that the adhesion of *C. albicans* to polyamides is higher

than to PMMA-based resins [24]. With regard to the different materials available, there are contradictory results concerning the adhesion and proliferation of *C. albicans*: While some authors demonstrated a significantly higher *Candida* colonization of PMMA than on silicone-based soft relining materials [80], other authors were able to demonstrate a lower colonization of PMMA with *C. albicans* as compared to the soft relining materials [6]. A possible explanation for these varying results could be related to the porosity of soft relining materials, which may harbor a large number of *Candida* cells in their pores and make them inaccessible for analysis, thus conceivably falsifying the results [80]. It could also be shown that materials with high surface energies such as urethane dimethacrylate (UDMA) and silicone displayed higher colonization with *C. albicans* than materials with comparatively lower surface energies [53]. The proportion of hyphae on silicone-based materials was higher than on UDMA- or PMMA-based materials [98].

In this regard, it is worth considering that most of the present investigations, especially with respect to the analysis of the adhesion of *C. albicans* to different denture base materials, have been carried out under experimental conditions; this means that the settings are often not very comparable and this is further complicated by the fact that clinical investigations barely exist. In spite of this, based on the available data, it can be concluded that for the production of denture bases, hydrophilic materials should be used as far as possible, as well as materials that have the lowest possible initial roughness after production; in this manner, porosities, and thus niches for biofilm formation, can be minimized in order to reduce biofilm-associated diseases.

3. Microorganisms change materials

Every material that is introduced into the oral cavity is subject to an ageing process as a result of use. The surfaces of removable dentures are no exception and they show signs of ageing and fatigue due to the daily mechan-

ical, thermal and chemical stress during use and cleaning [90]. In the long term, this can lead to surface roughness, discoloration and odor. In addition, the moisture in the oral cavity and the moist extraoral storage environment cause the material to absorb water, which varies in extent depending on the material, and can lead to a reduction in the strength of the material [99]. It appears that thermoplastics absorb less water than cured resin materials [45]. Drying of the denture in turn can lead to distortion and a reduced accuracy of fit, although, shorter drying phases can reduce the formation of bacteria on the surface of the material [90]. In addition, microorganisms play a decisive role in the modification of polymer denture materials [8, 26, 39, 84]. Even pellicle intercalation between the matrix and filler material can cause fillers to dissolve out of the resin composite, and thus, favor the polymer's deterioration. Some of the enzymes that are secreted by microorganisms [13], in addition to acids, can degrade material surfaces [12, 65]. This can increase the surface roughness of the materials [74], which on the one hand, promotes bioadhesion, while also simultaneously irritating the mucosa in contact. This phenomenon seems to affect the polymer materials of older generations especially [74]. Therefore, the use of newer generation polymer materials as well as regular professional cleaning and polishing of polymer-based restorations seem to be recommendable. However, no clinical or experimental data is available to date regarding the long-term durability of modern materials that are used for the fabrication of removable dentures such as PAEKs or CAD/CAM-processed PMMA [96].

4. Future prospects

Removable dentures will play an important role in dental prosthetics in the foreseeable future. Due to the current demographic trends, an increasing number of older patients are being treated with dentures. Since regular and adequate removal of biofilms from the surface of removable dentures cannot be ensured in all cases, it would be desirable to devel-

op materials and strategies that make the biofilm accumulation on, and the removal from, denture surfaces manageable and predictable. Currently, the available data from clinical studies regarding the interaction between polymeric materials of removable dentures and biofilms is rather sparse. The first reported results for modern polymeric materials with optimized material properties have been promising. Further strategies that promise the easy removal of adherent biofilms from the surface of denture base materials have so far only been described in very limited laboratory studies, mostly with a different background. At the moment, research regarding clinical applications is still pending.

Conflicts of interest

The authors declare that there is no conflict of interest within the meaning of the guidelines of the International Committee of Medical Journal Editors.

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