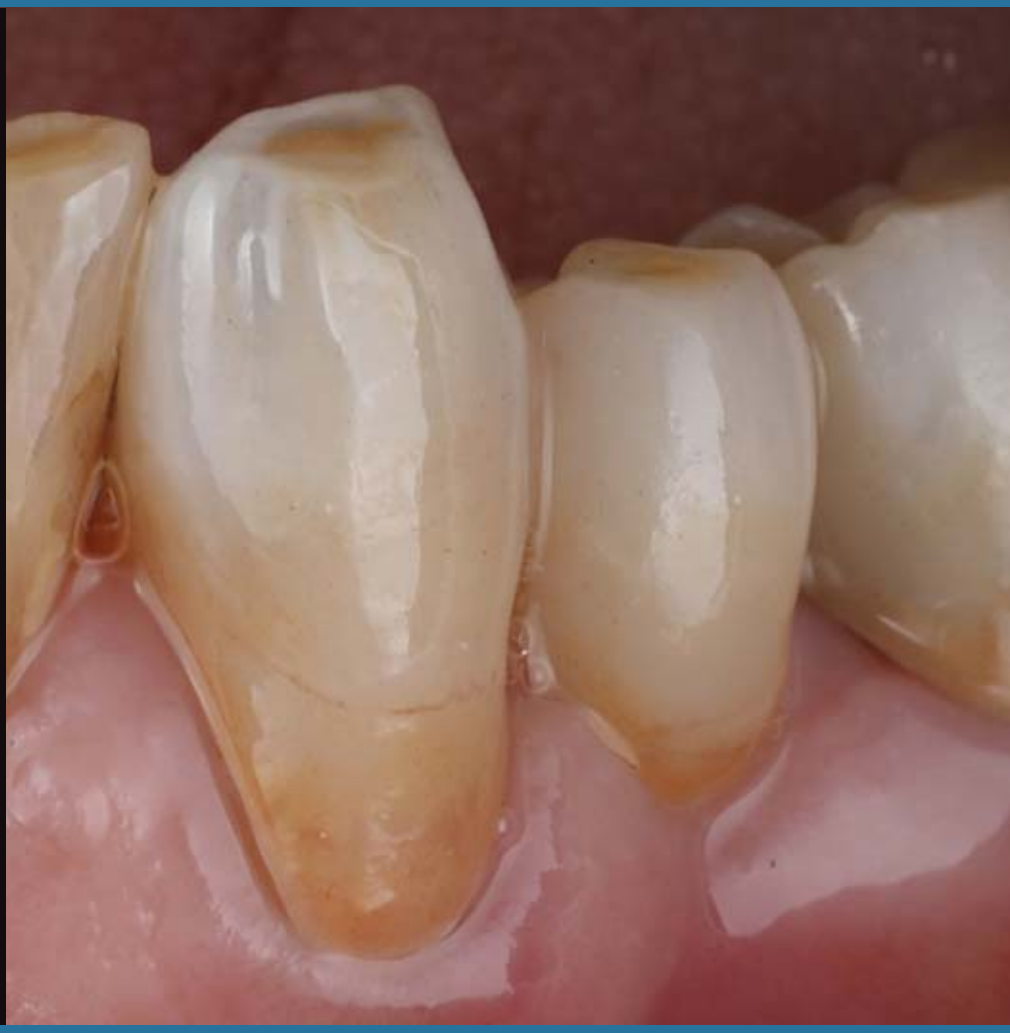
6 | 2021
3. VOLUME

DZZ
INTERNATIONAL

German Dental Journal International – **www.online-dzz.com**
International Journal of the German Society of Dentistry and Oral Medicine



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

Deutscher Ärzteverlag

PRACTICE

RESEARCH

Title picture: From original article by Jerg, Spitznagel, Gierthmühlen et al.: Update of the S3 guideline "All-ceramic single crowns and fixed dental prostheses" – current evidence-based recommendations, pp. 250–258. Figure 2: Clinical case of an all-ceramic 3-unit posterior FDP made of monolithic zirconia. c) treatment completion. (Photo: P. Gierthmühlen)
Online-Version of DZZ International: www.online-dzz.com

Matthias G. Hautmann

Position paper: Does radiotherapy play a role in activated osteoarthritis of the temporomandibular joint?

Topic: Could radiotherapy be a treatment option for symptomatic inflammatory and/or degenerative arthropathy of the temporomandibular joint?

Background

In addition to radiotherapy for malignant tumors, radiotherapy for non-malignant diseases also plays an important role in daily clinical practice and it is applied successfully [17, 24]. Although radiotherapy is used much more frequently to treat malignant diseases, several national patterns of care studies have shown the relevance of radiotherapy for treating non-malignant diseases. The last large national patterns of care study revealed that more than 37,000 patients per year are irradiated for non-malignant diseases. In this case, only a small proportion are benign tumors. The majority of cases consist of degenerative and degenerative-inflammatory diseases, followed by functional diseases and hyperproliferative diseases. Degenerative and degenerative-inflammatory diseases alone account for more than 23,000 cases per year in Germany [25]. Consequently, the interesting question arises of whether patients with degenerative or degenerative-inflammatory diseases of the TMJ can also benefit from radiotherapy.

Among the degenerative and degenerative-inflammatory diseases, plantar fasciitis (with or without accompanying heel spur), enthesiopathy, tendinitis, epicondylitis, and subacromial syndrome play an important role [17, 24, 25]. In a large percentage, many of these diseases can be cured or at least significantly improved by means of radiotherapy. For example, in plantar fasciitis, radiotherapy is a standard therapy. The effect has been demonstrated in numerous prospective, randomized studies [18, 24].

Radiotherapy for the treatment of osteoarthritis has been an established procedure for many years. The beginnings of radiotherapy in the treatment of arthritic changes dates back to the 1920s [11, 15, 16, 28]. However, there is little data on radiotherapy for osteoarthritis or activated osteoarthritis of the TMJ. Most existing data relates to knee joint arthritis, hip arthritis and finger polyarthritsis. In many heterogeneous collectives, TMJ osteoarthritis is lost in the "other" arthritides. Only one older study reports TMJ osteoarthritis separately [2, 4, 11].

The current S2k-Guideline of the DEGRO (German Society for Radiation Oncology) provides a "should" recommendation for gonarthritis and a "can" recommendation for other arthritides. Thus, according to the guideline's recommendations, there is also the possibility to employ irradiation in the treatment of osteoarthritis or degenerative and/or inflammatory arthropathies of the TMJ [16, 17, 20]. The author's research group has been successfully treating patients with TMJ osteoarthritis using radiotherapy for several years. Most of these patients are included in a national multicenter observational study.

Principles of radiobiology

Many preclinical studies have shown that low-dose radiotherapy has an inflammation-modulating or anti-inflammatory effect via different mechanisms. For example, a reduction of chemotactic cytokines (e.g., CCL20) has been shown. Thus, fewer inflammatory cells are attracted [17, 22].

One of the most important stages in the inflammatory cascade is the adhesion of monocytes and granulocytes to the endothelium and the migration of these immune cells into the inflamed tissue. One mode of ac-

Clinic and Polyclinic for Radiotherapy, University Hospital Regensburg, 93042 Regensburg: PD Dr. Matthias G. Hautmann
Translation from German: Cristian Miron
Citation: Hautmann MG: Position paper: Does radiotherapy play a role in activated osteoarthritis of the temporomandibular joint? Dtsch Zahnärztl Z Int 2021; 3: 242–245
DOI.org/10.3238/dzz-int.2021.0029

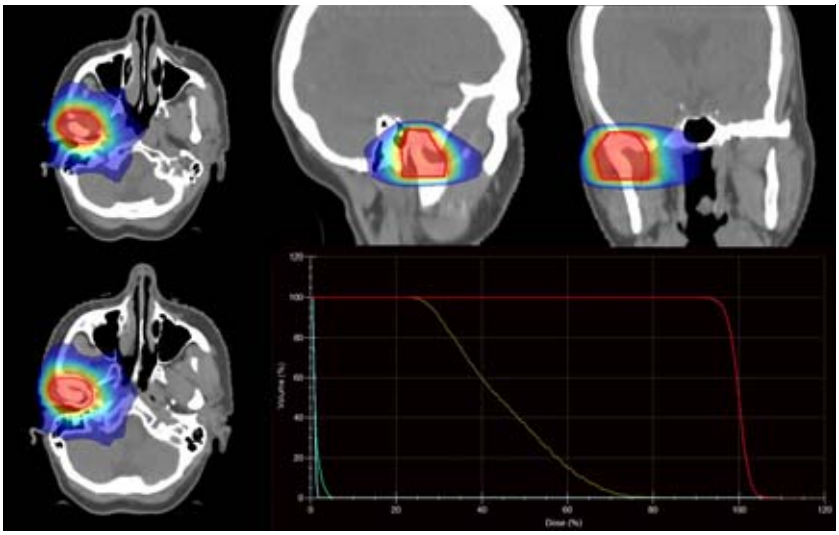


Fig. 1: M. G. Hautmann

Figure 1 Radiotherapy plan for a patient who has been irradiated unilaterally at the TMJ. The figures on the left and above show the dose distribution in various 3D cross sections: two transversal, one sagittal and one coronal. The target volume is outlined in red. The figure on the bottom right shows a dose-volume histogram which is used to estimate the dose distribution in the target volume and the dose exposure of the organs at risk.

tion of low-dose radiotherapy is to attenuate this adhesion process. Interestingly, this effect is independent of the target irradiated (that is, whether the immune cells or the endothelial cells are irradiated) [17, 21, 24].

The release of anti-adhesive cytokines also seems to be a starting point for the immunomodulatory or anti-inflammatory effect of low-dose radiotherapy [17]. Apoptosis of inflammatory cells (especially granulocytes and monocytes) likewise appears to play a role [6].

Another important target that is related to the analgesic and anti-inflammatory effects of low-dose radiotherapy is the attenuation of nitric oxide synthase and thus nitric oxide production. Nitric oxides are an important carrier of the inflammatory response and are strongly involved in inflammatory pain [17, 21].

Similar to nitric oxide synthesis, the formation of reactive oxygen metabolites, important contributors to inflammation, is also reduced [17].

What is common to these anti-inflammatory mechanisms is that their maximum effect is in the range of low-dose radiotherapy (doses between 0.3 and 1.0 Gy). At higher radiation doses, there does not seem to be an increased anti-inflammatory effect, but rather, a weaker effect can be assumed [5, 21].

These mechanisms have now been relatively well-studied at the molecular level or in cell experiments. The effect has also been demonstrated in animal models. Moreover, there are also clinical studies demonstrating that these models are applicable to patients and that low-dose radiotherapy has immunomodulatory or anti-inflammatory effects in various disease conditions [3, 5, 7, 8, 27].

Principles of radiation physics

What radiotherapy of various degenerative and degenerative-inflammatory diseases has in common is that low radiation doses are used, usually individual doses between 0.5 and 1.0 Gy. Total doses of 3.0–6.0 Gy are usually applied. In most cases, irradiation is not performed daily, but 2–3 times a week [20, 21].

In contrast, in curative cases of malignant tumors, radiation doses of around 50 Gy are generally used in multimodal therapy approaches, and over 60 Gy in definitive radiotherapy.

Irradiation of non-malignant diseases can be performed with a linear accelerator (using photon or electron radiation) or, in part, with an orthovoltage device. A linear accelerator should be used for irradiation of activated TMJ osteoarthritis. As part of the planning, 3D CT planning should be integrated – ideally MRI-guided – in order to protect surrounding tissue and organs at risk [2,21].

Current evidence on radiotherapy for osteoarthritis

Since the 1920s, there have been a large number of publications showing the benefit of radiotherapy in patients with osteoarthritis. As of 2019, the author's research group has identified a total of 50 publications with over 12,000 patients who have been evaluated [11, 15]. In recent years, however, there have been 2 randomized studies on knee osteoarthritis and finger polyarthrosis, each with a smaller number of patients, that failed to show a significant benefit [13, 14]. This is in contrast to the many other studies that point to a benefit for patients – all the more so because there are also several studies that have used objectifiable criteria to demonstrate responsiveness [8, 19]. In this regard, one assumption as to why these two randomized trials failed to show a significant benefit is that they probably included many patients with very advanced osteoarthritis. It is likely that several different pain components play a role in osteoarthritis. In addition to pain that is purely degenerative, there is also an important inflammatory pain component in activated osteoarthritis, respectively inflammatory or degenerative-inflammatory arthropathy. It can be assumed that radiotherapy can help improve the inflammatory pain component, in particular, but its effect on the purely degenerative pain component is insufficient [8, 19, 21, 27].

Clinical effect

Many studies have shown that the analgesic, respectively the anti-inflammatory, effect occurs with a certain latency [11, 18, 28], usually ranging between 2 and 6 weeks after the end of radiotherapy. Only a small proportion of patients experience an improvement in pain during or immediately after radiotherapy. The pain minimum is usually reached between 4 and 6 weeks after the end of radiotherapy. The evaluation of the success is therefore only possible with a time delay.

Figure 2 Design of a modern linear accelerator that can be used for the irradiation of malignant and non-malignant diseases.

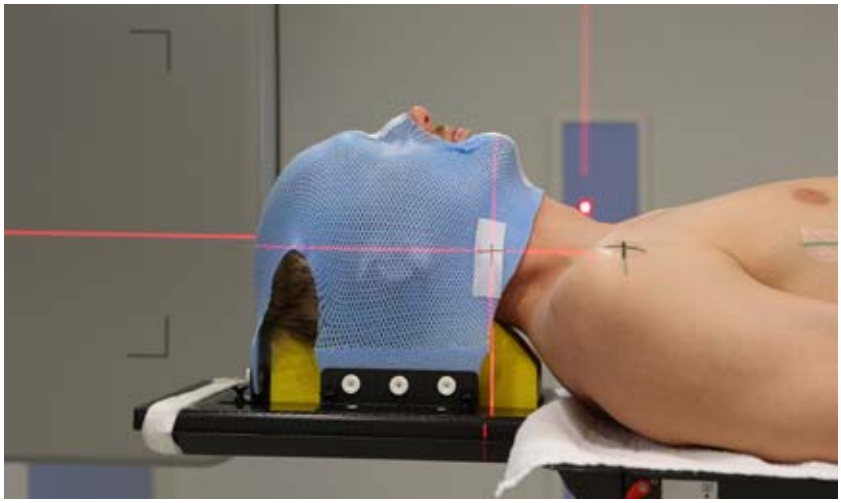


Figure 3 Positioning of the patient with a custom-made thermoplastic mask. The mask is used to immobilize the patient. A laser-guided coordinating system (drawn on the mask) helps align the patient correctly for irradiation.

Fig. 2 + and 3: UKR

The first clinical follow-up examination should generally take place 10–12 weeks after the end of radiotherapy. In case of an insufficient effect or lack of response, a new course of irradiation can be performed. Clinical studies have shown the benefit of such re-irradiation in degenerative or degenerative-inflammatory diseases, even in patients who did not show a response in the first course [9, 10].

Unlike enthesopathies (tendon attachment diseases) or tendinitides (tendon inflammations), in osteoarthritis, the analgesic effect of radiotherapy is often not permanent, but only present for a few years. This is most likely explained by the degenerative pain component of osteoarthritis. In addition, osteoarthritis constitutes a progressive clinical pattern with further progressive degeneration [11, 16, 18, 20].

Since recent data suggests that predominantly or exclusively the inflammatory pain component can be favorably influenced by low-dose radiotherapy, patients with activated osteoarthritis – ideally patients in the activated relapse of osteoarthritis – should be treated particularly [19].

Whether analgesic or anti-inflammatory radiotherapy can slow down progression has not yet been clearly proven. There are – predominantly preclinical – studies that may suggests this [3, 5, 27].

Risks of radiotherapy in the treatment of degenerative and degenerative-inflammatory diseases

Since low-dose radiotherapy is used for treatment – as mentioned above – so-called deterministic toxicities are not to be expected. These include typical side effects such as radiodermatitis or mucositis. The typical late side effects of higher-dose radiotherapy such as fibrosis or xerostomia are also not to be expected, or can be virtually ruled out, as the tolerance doses of the organs at risk are generally not reached or by far not reached [17, 21, 23].

In principle, there is a risk of stochastic side effects (e.g. tumor induction) with each application of radiation on humans. This risk of tumor induction is low in the case of radiotherapy for degenerative and degenerative-inflammatory diseases. The effective dose model can be used to estimate this risk. However, individual factors such as gender and age of the patient must still be accounted for in the assessment. The potential chance of improvement and the risks of alternative therapy options must be weighed against this risk [2, 21, 26].

For example, there is a significant risk of adverse side effects and also severe adverse side effects when analgesic drugs are taken for a longer period of time. In many cases, this risk outweighs the risk of radiotherapy [1].

In a calculation according to ICRP 2008, for an intermediate-aged patient who is irradiated unilaterally at the TMJ with a dose of 6 × 0.5 Gray, there is an estimated lifetime risk of approximately 0.008 % for the induction of a malignant tumor [2, 26].

Practical approach

Patients with activated osteoarthritis of the TMJ may also be referred for radiotherapy by dentists [12]. It should be noted that a referral is required for radiotherapy appointments. It is also advisable to send the most important documents and information in advance (provided the patient agrees to this after being informed in accordance with data protection regulations). In particular, the previous course of the disease, the course of treatment, and available cross-sectional imaging (e.g. CT or

MRI) with corresponding radiological findings are very relevant.

Conclusion

Low-dose radiotherapy for treating osteoarthritis of the TMJ is a conservative treatment option. In particular, it can be applied in cases of activated osteoarthritis as well as inflammatory or degenerative-inflammatory arthropathies. Even if patients having TMJ osteoarthritis are underrepresented in the studies to date, treatment can be provided in analogy to osteoarthritis at other sites, with the aim of achieving analgesic and anti-inflammatory effects. This is also in line with the recommendation of the S2k-Guideline of the DEGRO.

The treatment utilizes low doses of irradiation. Typical deterministic toxicities are not expected and the risk of stochastic side effects appears to be low.

Conflict of interest

The author declares that there is no conflict of interest as defined by the guidelines of the International Committee of Medical Journal Editors.

References

1. Aygün D, Kaplan S, Odaci E, Onger ME, Altunkaynak ME: Toxicity of non-steroidal anti-inflammatory drugs: a review of melatonin and diclofenac sodium association. Histol Histopathol 2012; 27: 417–436

2. Behr M, Fanghänel J (Hrsg): Kraniomandibuläre Dysfunktionen. Antworten auf Fragen aus der Praxis. Thieme, Stuttgart 2019

3. Budras KD, Hartung K, Münzer BM: Licht- und elektronenmikroskopische Untersuchungen über den Einfluss von Röntgenbestrahlung auf das Stratum synoviale des entzündeten Kniegelenks. Berl Munch Tierarztl Wochenschr 1986; 99: 148–152

4. Cocchi U: Erfolge und Mißerfolge bei Röntgenbestrahlung nichtkrebsiger Leiden. Strahlenther 1943; 73: 255–305

5. Frey B, Gaipl US, Sarter K et al.: Whole body low dose irradiation improves the course of beginning polyarthritis in human TNF-transgenic mice. Autoimmunity 2009; 42: 346–348

6. Gaipl US, Meister S, Lödermann B et al.: Activation-induced cell death and total Akt content of granulocytes show a biphasic course after low-dose radiation. Autoimmunity 2009; 42: 340–342

7. Hautmann AH, Wolff D, Hilgendorf I et al.: Total nodal irradiation in patients with severe treatment-refractory chronic graft-versus-host disease after allogeneic stem cell transplantation: Response rates and immunomodulatory effects. Radiother Oncol 2015; 116: 287–293

8. Hautmann MG, Jung E-M, Beyer LP et al.: Ist die Strahlentherapie eine effektive Behandlungsoption der Bakerzyste? Strahlenther Onkol 2019; 195: 69–76

9. Hautmann MG, Neumaier U, Kölbl O: Re-irradiation for painful heel spur syndrome. Retrospective analysis of 101 heels. Strahlenther Onkol 2014; 190: 298–303

10. Hautmann MG, Rechner P, Hipp M et al.: Rebestrahlung bei Arthrose – retrospektive Analyse von 217 Gelenken. Strahlenther Onkol 2019; 195: 1060–1067

11. Hautmann MG, Rechner P, Neumaier U et al.: Radiotherapy for osteoarthritis – an analysis of 295 joints treated with a linear accelerator. Strahlenther Onkol 2020; 196: 715–724

12. Kassenzahnärztliche Bundesvereinigung, Spitzenverband Bund der Krankenkassen: Bundesmantelvertrag – Zahnärzte (BMV-Z) 2021

13. Mahler EAM, Minten MJ, Leseman-Hoogenboom MM et al.: Effectiveness of low-dose radiation therapy on symptoms in patients with knee osteoarthritis: a randomised, double-blinded, sham-controlled trial. Ann Rheum Dis 2019; 78: 83–90

14. Minten MJM, Leseman-Hoogenboom MM, Kloppenburg M et al.: Lack of beneficial effects of low-dose radiation therapy on hand osteoarthritis symptoms and inflammation: a randomised, blinded, sham-controlled trial. Osteoarthritis Cartilage 2018; 26: 1283–1290

15. Minten MJM, Mahler E, Broeder AA den, Leer JWH, van den Ende CH: The efficacy and safety of low-dose radiotherapy on pain and functioning in patients with osteoarthritis: a systematic review. Rheumatol Int 2016; 36: 133–142

16. Mücke R, Seegenschmiedt MH, Heyd R et al.: Strahlentherapie bei schmerzhafter Kniegelenkarthrose (Gonarthrose): Ergebnisse einer deutschen Patterns-of-Care-Studie. Strahlenther Onkol 2010; 186: 7–17

17. Mücke R, Micke O, Seegenschmiedt MH: Strahlentherapie gutartiger Erkrankungen. S2e-Leitlinie der Deutschen Gesellschaft für Radioonkologie (DEGRO). 2018

18. Niewald M, Seegenschmiedt MH, Micke O et al.: Randomized, multicenter trial on the effect of radiation therapy on plantar fasciitis (painful heel spur) comparing a standard dose with a very low dose: mature results after 12 months' follow-up. Int J Radiat Oncol Biol Phys 2012; 84: e455–62

19. Ott OJ, Micke O, Mücke R et al.: Low-dose radiotherapy: Mayday, mayday. We've been hit! Strahlenther Onkol 2019; 195: 285–288

20. Ott OJ, Niewald M, Weitmann H-D et al.: DEGRO guidelines for the radiotherapy of non-malignant disorders. Part II: Painful degenerative skeletal disorders. Strahlenther Onkol 2015; 191: 1–6

21. Reichl B, Block A, Schäfer U et al.: DEGRO practical guidelines for radiotherapy of non-malignant disorders: Part I: Physical principles, radiobiological mechanisms, and radiogenic risk. Strahlenther Onkol 2015; 191: 701–709

22. Rödel F, Hofmann D, Auer J et al.: The anti-inflammatory effect of low-dose radiation therapy involves a diminished CCL20 chemokine expression and granulocyte/endothelial cell adhesion. Strahlenther Onkol 2008; 184: 41–47

23. Ruppert R, Seegenschmiedt MH, Sauer R: Radiotherapie von Arthrosen. Indikation, Technik, klinische Ergebnisse. Orthopade 2004; 33: 56–62

24. Seegenschmiedt MH, Makoski H-B, Trott K-R et al.: Radiotherapy for non-malignant disorders. Springer, Berlin, Heidelberg 2008

25. Seegenschmiedt MH, Micke O, Willich N: Radiation therapy for nonmalignant diseases in Germany. Current concepts and future perspectives. Strahlenther Onkol 2004; 180: 718–730

26. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. Ann ICRP 2007; 37: 1–332

27. Trott KR, Parker R, Seed MP: Die Wirkung von Röntgenstrahlen auf die experimentelle Arthritis der Ratte. Strahlenther Onkol 1995; 171: 534–538

28. Zschache H: Ergebnisse der Röntgenschwachbestrahlung. Radiol Diagn (Berl) 1972; 13: 181–186

Photo: UKR

PD DR. MATTHIAS G. HAUTMANN,
Clinic and Polyclinic for Radiotherapy,
University Hospital Regensburg,
93042 Regensburg

Painful bites: Publication invitations from online journals

On August 6, 2021, at 0:05 a.m., I received an e-mail requesting submission of a manuscript for the first issue of an online dental journal with the euphonious but hitherto unknown title *Journal of Dentistry and Oral Medicine* (Fig. 1).

Already in the cover letter, some conspicuous features stand out: besides the time (which can still be justified because of the six-hour time difference), the inappropriate salutation ("Dear jens.tuerp") and the unusual introductory wording ("Welcome …!!"), the wide range of content covered by the journal ("all types of articles"), the emphasis on the professional qualifications of the editorial board, and the extremely short deadline of 10 days for submitting a manuscript, among other things, catched the eye.

When one receives such an e-mail, there are two options: you delete it right away (which is not bad advice) or you take a closer look to get an idea of its level of seriousness (not bad advice either). I decided to go with the latter.

The *Journal of Dentistry and Oral Medicine* is, according to the self-description on its website, an "international peer reviewed open access journal primarily focused on research and clinical aspects of dentistry and oral medicine". It claims to cover all areas of dentistry in terms of content and lists 46 subject headings to that end, from *Bone Regeneration* to *Traumatology*. The journal is launched by *Inquest Publications,* an online publisher based in Urbana, Maryland (USA). Its website (www.inquestpublications.com/) lists 49 other online medical journals. As far as presentation and content (including some grammatical and orthographical errors) are concerned, the website does not differ from those of comparable providers.

Dear jens.tuerp ,

Welcome…!!

I invite you to submit an article to "Journal of Dentistry and Oral Medicine", which is a peer-reviewed, open access journal that publishes all types of articles.
Currently we are accepting article submission for the Debut Issue of the journal.

The journal has a distinguished Editorial Board with extensive academic qualifications, ensuring that the journal maintains high scientific standards and has a broad international coverage. Please Click here for EB members.

Manuscripts should be submitted to the journal at dentistry@inquestpublications.com on or before August 16th, 2021.

We would really appreciate if you participate in this issue.

Please do not hesitate to contact us if you have any questions about the journal.

Best regards,
Helen Alberto,
Journal Manager
http://www.inquestpublications.com/

Figure 1 The e-mail from August 6, 2021.

The editorial board presents 21 members from 9 countries: Brazil (1 person), France (2), India (4), Italy (6), Malaysia (3), Romania (1), Saudi Arabia (1), Serbia (1), and Turkey (2).

Name	Number
L R	115
F D	72
F E	70
L L	65
R X	32
P A	30
M M	29
A I	29
N M	23
S P	23
C F	18
H I	14
R A	11
K M	10
P P	10
O B	8
B A	5
V L	4
A D	3
S O	2
C D	2

Table 1 Number of PubMed-listed articles of the 21 editorial board members. These are indicated by their initials (last name, first name).

Department of Oral Health & Medicine, University Center for Dental Medicine Basel UZB: Jens C. Türp, DDS, Dr med dent, MSc, M.A., Professor
Citation: Türp JC: Painful bites: Publication invitations from online journals. Dtsch Zahnärztl Z Int 2021; 3: 246–247
DOI.org/10.3238/dzz-int.2021.0030

Article Types	Costs
Funded Research	$2,200
Research	$1,200
Review	$1,000
Short Article	$500

Table 2 Article processing charges.

An analysis of the PubMed-based publication performance of the 21 board members shows that only 4 (invariably Italian) individuals have a strong presence (65 to 115 articles) in this meta-database. In contrast, 6 members are moderately represented (in the range of 20 to 30 publications), while the remaining 11 members have a weak presence (less than 20 publications). In view of this composition, to speak overall of a "distinguished Editorial Board with extensive academic qualifications" (Fig. 1) seems daring – the 4 colleagues from Italy are explicitly excluded from this statement.

Inquest Publications points out that readers of the published articles are not charged for accessing them. However, this should generally be assumed for purely online journals. On the other hand, once a submitted manuscript has been accepted, authors are charged a considerable fee for processing their article (Tab. 2).

Irrespective of the question about the quality of the review process of submitted manuscripts, i.e., whether peer review worthy of its name is really carried out, there is another point to take into account: it is not guaranteed that the journal will be listed in the foreseeable future in the well-known medical databases, such as PubMed, Livivo, and Directory of Open Access Journals. In any case, limiting access to the (largely unknown) *Inquest Publications* website is a barrier to the dental community's reception of the publications. Moreover, it is quite possible that published articles will eventually no longer be accessible. A look at the other 49 journal titles reveals (www.inquestpublications.com/journals.html □ "Articles") that so far articles have been published in only 15 journals, and in modest numbers (total 35, minimum 1, maximum 5, median 2 articles per journal [not per issue!]).

Whether one would like to consider publishing in this journal or in online journals of comparable providers under these circumstances is something everyone may decide for themselves. But actually, the answer should be clear.

Conflict of interest

The author declares that there is no conflict of interest as defined by the guidelines of the International Committee of Medical Journal Editors.

Photo: Basilisk, Basel

JENS C. TÜRP
DDS, DR MED DENT, MSc, M.A., PROFESSOR
Department of Oral Health & Medicine
University Center for Dental Medicine
Basel UZB
Mattenstrasse 40
CH-4058 Basel, Switzerland
jens.tuerp@unibas.ch

Annika Jerg, Frank Spitznagel, Oliver Ahlers, Jörg Beck, Florian Beuer, Rainer Struck, Kerstin Christelsohn, Bernd Reiss Jan Frederik Güth, Matthias Kern, Petra Gierthmühlen

Update of the S3 guideline "All-ceramic single crowns and fixed dental prostheses" – current evidence-based recommendations

Summary: In the update of the S3 guideline "All-ceramic single crowns and fixed dental prostheses" (AWMF Reg. No. 083-012) published in June 2021, new scientific evidence was incorporated into the guideline first published in 2014. The guideline established a broadly consented, evidence-based framework within which the use of tooth-supported all-ceramic restorations offers comparable long-term clinical outcomes to metal-based crowns and fixed dental prostheses (FDPs).
In the updated version (version 2.0), all chapters have been reviewed with regard to new research findings, backgrounds have been newly discussed, and numerous recommendations have been updated with regard to indications and localization. In the process, the recommendation grading of individual materials was adjusted on the basis of new literature. Recommendations on materials that are no longer on the market (alumina ceramics) were removed and recommendations on new materials and applications were added (zirconium oxide ceramics [3Y-TZP] monolithic; zirconium oxide ceramics [4Y-, 5Y-TZP and combinations with these]; resin-matrix ceramics; lithium silicate/phosphate glass-ceramics). Recommendations on endocrowns were also made for the first time. In addition, the questions regarding the treatment of bruxism patients with all-ceramic restorations as well as material-specific manufacturing recommendations were re-evaluated.
The main recommendations are listed in this article, the key innovations are emphasized, and the considerations of the guideline group in arriving at the recommendations are summarized. All recommendations as well as complete references can be found in the long version of the German S3 guideline [11].

Key words: guideline; prosthodontics; crowns; fixed dental prostheses; all-ceramics; survival rates; restorative materials

Department of Prosthodontics, Medical Faculty and University Hospital Düsseldorf, Heinrich-Heine-University, 40225 Düsseldorf: Dr Annika Jerg (corresponding author), Dr Frank Spitznagel, Prof. Dr Petra Gierthmühlen
Methodological accompaniment: Dr Susanne Blödt (AWMF), Dr Anke Weber (DGZMK, Leitlinienbeauftragte), Dr Silke Auras (DGZMK, Leitlinienbeauftragte)
Translation from German: Yasmin Schmidt-Park
Citation: Jerg A, Spitznagel F, Ahlers O, Beck J, Beuer F, Struck R, Christelsohn K, Reiss B, Güth JF, Kern M, Gierthmühlen P: Update of the S3 guideline "All-ceramic single crowns and fixed dental prostheses" – current evidence-based recommendations. Dtsch Zahnärztl Z Int 2021; 3: 248–256
DOI.org/10.3238/dzz-int.2021.0031

1 Introduction

The reasons for preparing and updating the guideline "All-ceramic single crowns and fixed dental prostheses" were the continuous further development in the field of all-ceramic materials and the continuing prevalence of severely destroyed and missing teeth requiring treatment with crowns and fixed dental prostheses (FDPs) [28]. The guideline focuses on tooth-supported crown and tooth-supported FDPs; partial crowns, inlays, onlays and repositioning onlays are not covered by the guideline.

All tooth-colored materials must compete with metal-based restorations, which are still considered as the gold standard for fixed restorations [42, 66, 88]. Since the clinical performance of tooth-colored materials strongly depends on the indication, the materials used and their processing [18, 39, 44, 68, 69], evidence- and consensus-based recommendations have been made which take these influencing factors into account.

The recommendations of the guideline refer to the survival and complication rates of all-ceramic crowns and fixed dental prostheses, which have been evaluated based on long-term clinical studies and thus serve as a decision criterion. This provides the patient and restorative treatment team with therapeutic safety, and complications can be avoided.

The recommendations of the present update were based on a new systematic literature search, which included 24 new studies. The content of the new literature was evaluated regarding the survival rates of the restorations and the complications that occurred, as well as methodologically with evidence levels (Table 1). Depending on the study quality, the number of studies and the study results, recommendations of varying strength (Table 2) emerged from this, which were adopted in a structured consensus procedure (for consensus strengths, see Table 3).

Evidence Assessment	
1++	High quality meta-analyses, systematic literature reviews of randomized controlled trial (RCT) articles, or RCTs with a very low risk of bias
1+	Well-conducted meta-analyses, systematic literature reviews, or RCTs with a low risk of bias
1–	Meta-analyses, systematic literature reviews, or articles on RCTs with a high risk of bias
2++	High quality systematic literature reviews or articles on case-control studies or cohort studies
2+	Well-conducted case-control studies or cohort studies with a low risk of influence or bias and a moderate probability that the associations are causal, and well-conducted case series with an acceptable risk of bias
2–	Articles on case-control studies with a high risk of influence or bias and a significant risk that the associations are not causal
3	Articles on non-analytical studies, e.g. case presentations or case series
4	Expert opinion

Table 1 Qualitative evidence assessment (LoE = Level of Evidence) modified and deviating from SIGN 50 (Scottish Intercollegiate Guidelines Network).

	Evidence strength	Recommendation	Recommendation against intervention	Description
A	high	should ↑↑	should not ↓↓	Strong recommendation
B	moderate	should ↑	should not ↓	Recommendation
0	low	may be used/ may be indicated =	may not be used =	Recommendation open

Table 2 Scheme of recommendation grading according to AWMF

2 Fundamentals of materials science

2.1 Material classes

Silicate ceramics consist of a glass matrix with embedded crystals. A classic representative is feldspar ceramic. Silicate ceramics can be used as veneering ceramics, but can also be pressed or milled from industrially manufactured blocks [18, 89]. Lithium disilicate ceramics and lithium silicate ceramics containing zirconium oxide have an increased flexural strength of up to 400 MPa compared to other silicate ceramics [25, 89].

Oxide ceramics do not have a glass matrix, but usually consist of zirconia polycrystals stabilized with yttria [8, 55]. The flexural strength of classic first-generation tetragonal zirconia doped with 3 mol% yttrium is significantly increased to over 1000 MPa, but light transmission is limited and these materials are thus more opaque, making them suitable primarily as framework materials for manual veneering [72, 73]. With the novel generations of zirconium oxides available on the market, greater translucency is to be achieved by varying the yttria content among other modifications [91]. This is also the reason for the designations 3Y-, 4Y- or 5Y-TZP used in the guideline (3 = 3 mol-%; 4 = 4 mol-%; 5 = 5 mol-%; Y = yttrium oxide; TZP = "tetragonal zirconia polycristal"). More translucent zirconium with an

Classification of consensus strength	
Strong consensus	Consent from >95 % of the participants
Consensus	Consent from >75–95 % of the participants
Majority approval	Consent from >50–75 % of the participants
No consensus	Consent from <50 % of the participants

Table 3 Classification of consensus strength according to AWMF

increased content of yttrium has a larger cubic phase fraction and is offered by many manufacturers for monolithic use [91]. It should be noted that these modifications are at the expense of the mechanical properties and thus the range of indications can differ significantly depending on the zirconium material, generation and manufacturer [22]. Recently, multilayer blocks with a color and translucency gradient have also been offered for monolithic use, in which, for example, combinations of mechanically more stable 4Y-TZP and 5Y-TZP, which is optically more translucent in the incisal region, are used [2].

Resin-matrix ceramics (RMC) can be divided into two subgroups: CAD/CAM composites with dispersed fillers as well as a predominantly organic phase and polymer-infiltrated ceramics with a dominant inorganic phase [9, 38]. Depending on the material, both groups are intended for various single-tooth restorations; they are not approved by the manufacturers for FDPs due to their limited flexural strength of 150–240 MPa [9, 36].

2.2 Material selection

In addition to a range of silicate ceramics, various types of zirconium ceramics (3Y-TZP, 4Y-TZP, 5Y-TZP) are available for all-ceramic single crowns and FDPs – each as an alternative to metal-based restorations. A trend towards monolithic materials can be observed, which allows less invasive preparation forms due to lower material thicknesses, preserves tooth structure, and expands the range of indications for all-ceramic restorations [4, 86].

The decision for a material depends on both material-related (esthetic potential, mechanical properties, abrasion behavior of the material and the antagonist) and clinical factors (degree of destruction of the tooth, cementation options, functional aspects). The clinical long-term success is closely linked to the correct indication, the experience and knowledge of the restorative team, as well as suitable cementation and an adequate occlusal concept.

3 Material recommendations

Table 4 provides an overview of the all-ceramic materials that are recommended or rejected for specific indications and localizations. Background information on the recommendations is provided briefly below and in detail in the long version of the guideline.

3.1 All-ceramic single crowns in the anterior region

For the fabrication of all-ceramic single crowns in the anterior region, veneered lithium disilicate ceramics or veneered zirconium oxide ceramics (3Y-TZP) should be used. The recommendations have been strengthened compared to the first version of the guideline, as restorations made of these veneered materials, according to recent data, have very good survival rates of 86.1–100 % after 5–10 years for lithium disilicate ceramics [20, 74, 80, 83–86] and 88.5–100 % after 5 years for zirconium oxide ceramics [13, 21, 33, 45, 48, 50]. Chipping as a technical complication of veneered zirconium crowns has been reported with a frequency of 1.9–8.1 % after 5 years [21, 48].

An open recommendation is made for the monolithic use of lithium disilicate ceramics and zirconium oxide ceramics (3Y-TZP) due to the rather low level of evidence: The materials can be used. Short-term data after an observation period of 3 years show promising results with survival rates of 100 % for monolithic crowns made of zirconium oxide ceramic [4].

Monolithic (leucite-reinforced) silicate ceramics provide survival rates of 100 % and 98.9 % in the only two available studies after observation periods of 5 and 11 years, respectively [18, 90], so they should be used. Limited data are available for monolithic feldspar ceramics, so they can be used in the context of an open recommendation.

No statement can be made at present on newer zirconium oxide ceramics (4Y-TZP, 5Y-TZP), RMC and lithium silicate/phosphate glass-ceramics due to a lack of clinical data.

3.2 All-ceramic single crowns in the posterior region

Veneered or monolithic lithium disilicate ceramics should be used for the fabrication of all-ceramic single crowns in the posterior region. Both chairside CAD/CAM-fabricated monolithic lithium disilicate ceramic crowns and laboratory press-fabricated monolithic lithium disilicate ceramic crowns and veneered lithium disilicate ceramic restorations show good long-term results after 8.7–11 years with survival rates of 83.5–98.2 % [20, 41, 60, 74, 80, 83–86]. Due to the recent good data the recommendation could be strengthened compared to the first version of the guideline.

Monolithic (leucite-reinforced) silicate ceramics and veneered zirconia ceramics should be used, monolithic feldspar ceramics and monolithic zirconium oxide ceramics can be used. The recommendations for veneered and monolithic zirconium oxide ceramics have been strengthened accordingly. Monolithic (leucite-reinforced) silicate ceramics showed survival rates of 97.5 % and 99 % after 5 years, respectively [18, 90]. New long-term data are available for veneered zirconium oxide ceramics with good 5-year survival rates of 94–98.1 % [21, 33, 46, 48, 62, 87] with moderate chipping rates of 1.9–10 % after 5 years [21, 46, 48, 62]. Monolithic feldspar ceramics had

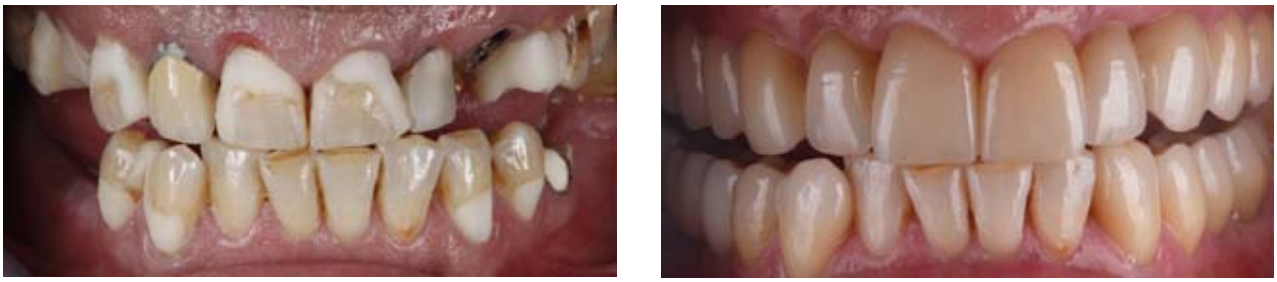


Figure 1 Clinical case a) Initial situation with teeth 12, 22 and 23 to be extracted. b) Treatment completion with FDP 11 to 13 made of vestibular veneered zirconium oxide ceramic, single crown 21 made of lithium disilicate ceramic. 22 and 23 are restored implant-prosthetically with an implant crown 23 with mesial cantilever 22 made of vestibular veneered zirconium oxide ceramic.

posterior survival rates of 99.6 % and 94.7–95 % after 7 and 12 years, respectively, in a cohort study and a case series [15, 52].

Expert consensus was expressed for monolithic zirconium oxide ceramics based on short-term data with 100 % survival after 3 years [4].

Due to insufficient scientific long-term data for newer zirconium oxide ceramics (4Y-TZP, 5Y-TZP), RMC and lithium silicate/phosphate glass-ceramics, no statement for a recommendation of their use in the posterior region can be made. Short-term studies with 2–3 years follow-up show survival rates of 92.9–96.8 % for polymer-infiltrated ceramics in the posterior region [7, 79].

3.3 All-ceramic endocrowns

Endocrowns were included in the guideline for the first time. Monolithic feldspar ceramics and monolithic as well as veneered lithium disilicate ceramics can be used. Initial data, however with a rather low level of evidence, show survival rates of 75–99.9 % after 7–12 years in the posterior region [3, 15, 51]. No evidence-based statement can yet be made on other all-ceramic materials when used as endocrowns.

3.4 All-ceramic 3-unit fixed dental prostheses in the anterior region

Veneered zirconia ceramics (3Y-TZP) should be used for the fabrication of all-ceramic 3-unit FDPs in the anterior region (Figure 1). This recommendation has been strengthened compared to the previous version of the guideline due to the large amount of new data. For example, after up to 7 years of follow-up, survival rates are 88.8–100 % [5, 33, 37, 43, 75, 90]. Data on technical complications are heterogeneous with chipping rates of 24.2 % at 5 years [5] and 7.4 % at 7 years [75].

Monolithic zirconium oxide ceramic (3Y-TZP) can be used and is thus recommended for this indication for the first time, but only on the basis of expert consensus. Clinical data after an observation period of 3 years show promising results with survival rates of 96.7 % for monolithic FDPs in the anterior and posterior region [23].

Monolithic and veneered lithium disilicate ceramics can also be used, since clinical data for veneered lithium disilicate ceramics in the newly considered literature show survival rates of 89.7 % and 86.1 % after 5–10 years, respectively [83]. In one study monolithic lithium disilicate ceramics have been followed up for longer with survival rates of 87.9 % after 10 years [32], that diminished however to only 48.6 % after 15 years [19].

No statement can be made on newer zirconium oxide ceramics (4Y-TZP, 5Y-TZP) due to a lack of clinical data.

3.5 All-ceramic 3-unit fixed partial dentures in the posterior region

Veneered zirconium oxide ceramics (3Y-TZP) should be used for the fabrication of all-ceramic 3-unit FDPs in the posterior region. This recommendation has been strengthened compared to the previous version of the guideline. After 5 years, survival rates are 90–97 % [5, 33, 43, 58, 69, 77, 90], and after 10 years, survival rates are 70.3–91.3 % [27, 53, 63, 64]. Since ceramic fractures such as chipping occur in up to 31 % of veneered zirconium oxide ceramic FDPs after 10 years, FDPs made of monolithic zirconium oxide ceramics are an alternative that can be used. Short-term data, a documented case series and initial empirical experience (case study in Figure 2) with monolithic and solely vestibular veneered FDPs made of zirconium oxide ceramics are promising: They show a survival rate after 3 years of 96.7 % for monolithic and 93.8 % and a chipping rate of 8.8 % for purely vestibular veneered FDPs [23], but still only receive a recommendation as an expert consensus.

Veneered and monolithic FDPs made of lithium disilicate ceramics show lower survival rates of 48.6–51.9 % after 10–15 years and 63.0–51.9 % after 5–10 years, respectively [19, 83], but can also be used within the manufacturer's indication. This rules out replacement of the 2nd premolar as well as the molars.

3.6 All-ceramic multi-unit/span fixed dental prostheses

The clinical data is not sufficient to recommend multi-unit/span all-ceramic FDPs. This was already the case when the first version of the guideline was prepared. The few existing studies on veneered zirconium oxide ceramics (3Y-TZP) report that there are increased chipping rates [63] at 35 % after 10 years and increased failures [71] with long-span FDPs. Survival rates are 75 % after 10 years for FDPs with up to 4-units [63] and 88.8 % after 7 years for FDPs with up to 6-units [75].

Indication	Localization	Material	LoE	Recommendation level	Recommendation level
Single crown	Anterior tooth region	Silicate ceramic (leucite reinforced), monolithic	2+	↑	B
		Feldspar ceramic, monolithic	4	=	0
		Lithium disilicate ceramic, veneered	2+	↑↑	A
		Lithium disilicate ceramic, monolithic	4	=	0
		Zirconium oxide ceramic (3Y-TZP), veneered	2+	↑↑	A
		Zirconium oxide ceramic (3Y-TZP), monolithic	4	=	0
	Posterior tooth region	Silicate ceramic (leucite reinforced), monolithic	2+	↑	B
		Feldspar ceramic, monolithic	2+	=	0
		Lithium disilicate ceramic, veneered	2+	↑↑	A
		Lithium disilicate ceramic, monolithic	2+	↑↑	A
		Zirconium oxide ceramic (3Y-TZP), veneered	2+	↑	B
		Zirconium oxide ceramic (3Y-TZP), monolithic	4	=	0
Endocrown	Posterior tooth region	Feldspar ceramic, monolithic	2+	=	0
		Lithium disilicate ceramic, veneered/monolithic	4	=	0
3-unit FDP	Anterior tooth region	Lithium disilicate ceramic, veneered	2+	=	0
		Lithium disilicate ceramic, monolithic	4	=	0
		Zirconium oxide ceramic (3Y-TZP), veneered	2+	↑↑	A
		Zirconium oxide ceramic (3Y-TZP), monolithic	4	=	0
	Posterior tooth region	Zirconium oxide ceramic (3Y-TZP), veneered	2+	↑	B
		Zirconium oxide ceramic (3Y-TZP), monolithic	4	=	0
	Posterior tooth region, replacement of the 1st premolar	Lithium disilicate ceramic, veneered/monolithic	2+	=	0
	Posterior tooth region, replacement of the 2nd premolar and molar replacement	Lithium disilicate ceramic, veneered/monolithic	2+	↓↓	A
Resin-bonded FDP	Anterior tooth region	Zirconium oxide ceramic, veneered	2+	↑↑	A
Inlay-retained FDP	Posterior tooth region	Lithium disilicate ceramic, monolithic	2+	↓↓	A
		Zirconium oxide ceramic (3Y-TZP), veneered	2+	↓↓	A

Table 4 Evidence- and consensus-based material recommendations. LoE = Level of Evidence, FDP = fixed dental prostheses

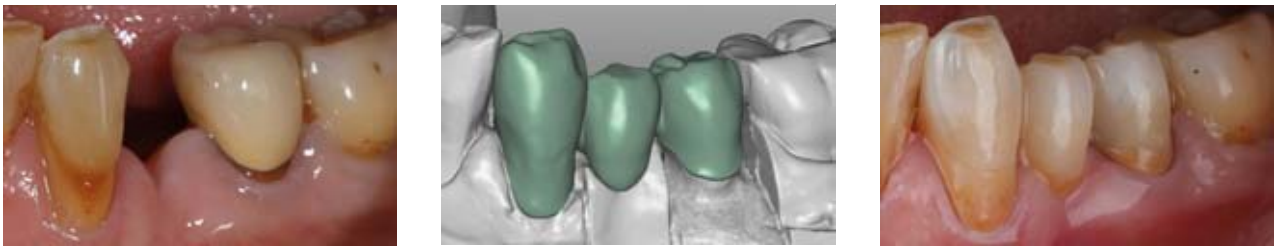


Fig. 1 + 2: P. Gierthmühlen

Figure 2 Clinical case of an all-ceramic 3-unit posterior FDP made of monolithic zirconia. a) initial situation, b) fully anatomical digital design, c) treatment completion

3.7 All-ceramic single retainer resin-bonded fixed dental prostheses in the anterior region

For the replacement of missing anterior teeth with all-ceramic single retainer resin-bonded FDPs, veneered zirconium oxide ceramics should be used, since these restorations show survival rates of 98.2 % after 10 years [31] and thus appear to be superior even to metal-ceramic resin-bonded FDPs [47, 57]. The recommendation was strengthened compared to the first version of the guideline.

3.8 All-ceramic single retainer resin-bonded fixed dental prostheses in the posterior region

Since no clinical data is available for the use of all-ceramic single retainer resin-bonded FDPs in the posterior region, their use cannot be recommended. This was already the case in the previous version of the guideline.

3.9 All-ceramic inlay-retained fixed dental prostheses in the posterior region

Lithium disilicate ceramics and veneered zirconium oxide ceramics should not be used for the fabrication of inlay-retained FDPs in the posterior region, since clinical data show low survival rates of 22 % after 15 years for lithium disilicate ceramics [1] and 12.1 % after 10 years for veneered zirconium oxide ceramics [59]. The negative recommendation for inlay-retained FDPs made of veneered zirconium ceramics was made for the first time on the basis of the new data. Approaches to design inlay-retained FDPs of veneered zirconium oxide ceramic with an additional wing resulted in a better survival rate of 95.8 % after 5 years [6]. Nevertheless, the data for other preparation forms and materials are not sufficient for a recommendation.

4 Bruxism and all-ceramics

The following strong expert consensus (100 % agreement) was reached on the question of whether all-ceramic restorations show comparable long-term results to metal-ceramic restorations in bruxism patients requiring crowns and FDPs:

Based on the current clinical study situation, the question cannot be conclusively evaluated [70], as a large number of studies explicitly excluded patients with bruxism [1, 5, 13, 15–17, 19, 20, 24, 27, 34, 35, 39, 46, 48, 53, 54, 59–65, 67, 69, 76, 78, 83, 84] and only a few studies explicitly included bruxism patients [2, 45, 49, 56, 74].

However, the clinical determination of whether patients suffer from bruxism has only been systematized in recent years. According to the S3 guideline Diagnostics and treatment of bruxism (AWMF register number 083–27), reliable detection of bruxism has so far only been possible by means of polysomnographic examinations [10]. Therefore, in practice, diagnosis remains limited to procedures that allow the diagnosis of "probable bruxism" but are associated with residual uncertainty [10]. In addition, the diagnosis of "bruxism" may change over the service time of the restorations.

Basically, the increased mechanical stress in patients with sleep and/or awake bruxism is a risk factor for all dental restorations, and therefore restorative treatments are associated with increased biological and technical risks [10].

In patients with probable bruxism, it is useful to check whether the treatment with metal restorations is possible and acceptable. If all-ceramic restorations are used, treatment with monolithic restorations is also an alternative. It is also important to inform the patient about the increased risk of loss due to bruxism and any restrictions on the indication provided by the manufacturer.

Protection against mechanical failure of the restorations can be provided by strict treatment protocols, careful analysis of function, and inclusion of an occlusal/stabilization splint.

5 Material-specific manufacturing recommendations

The following expert consensus was reached on the question of which material-specific manufacturing recommendations can be made: The preparation for all-ceramic crowns and FDPs with crown anchors should follow the proven preparation guidelines of the retention and resistance form [30] (consensus).

Minimally invasive preparation designs with 1 mm occlusal reduction were evaluated in only 2 studies: for monolithic and partially veneered crowns made of zirconium oxide ceramics in the anterior and posterior regions, an occlusal reduction of at least 0.5 mm was prepared in one study, with short-term survival rates of 98.5–100 % after 3 years [4]. For lithium disilicate ceramic crowns, an occlusal or incisal reduction of 0.2–2 mm was performed, and the survival rate in this study was 96.1 % after 9 years [86]. However, since no data beyond this are available for minimally invasive preparation forms for crowns and FDPs, no recommendation can be given (strong consensus).

Manufacturer's instructions and specifications of the Medical Devices Regulation must be strictly followed without fail (strong consensus). In addition, minimum layer thicknesses, connector cross-sections, framework design, processing, material treatment and the type of cementation must be observed (strong consensus). For example, subsequent grinding, surface roughness or temporary cementation may have a negative impact on the long-term survival of the restorations.

"A large proportion of failures were due to inadequate material dimensioning or other material failure such as chipping [12, 15, 21, 27, 46, 48, 53, 59, 62–64] and complete ceramic fractures [1, 17, 19, 26, 29, 39, 40, 45, 46, 59, 68, 69, 82]. Due to the potential risk of chipping, special attention should be paid to the type of veneer (full/partial)" [11].

6 Notes on the materials

- The manufacturer-dependent differences in composition within a material class as well as production-related features can lead to clinically relevant differences in the quality of results, without this necessarily being reflected in the literature.
- Regarding technical complications and the invasiveness of the preparation, the following should be considered: full veneering, purely vestibular veneering (watch glass setting) and veneering only in the incisal area ("cut-back").
- After any grinding measures on all-ceramic restorations, they must be polished again to a high gloss. This applies to all all-ceramic restorations. Otherwise, the adjusted area may be a predilection site for a subsequent ceramic fracture and promote wear of the antagonist [14, 81].

7 Conclusion

All-ceramic single crowns and FDPs provide good long-term results in terms of survival and freedom from complications if the indications are correct, the appropriate materials are selected and the procedure is carried out correctly. In particular, lithium disilicate ceramics and veneered zirconium oxide ceramics have proved very successful for anterior and posterior single crowns, 3-unit anterior FDPs and anterior resin-bonded FDPs. Monolithic zirconium oxide ceramics (3Y-TZP) can be used, but no statement can yet be made on newer materials such as translucent zirconia ceramics due to a lack of long-term data. All-ceramic multi-unit/span FDPs and all-ceramic inlay-retained FDPs are not recommended.

Conflict of interest

For possible conflicts of interest, see pp. 152–154 of the Guideline Report at: https://www.awmf.org/uploads/tx_szleitlinien/083–012m_S3_Vollkeramische_Kronen_Brücken_2021–06.pdf

References

1. Becker M, Chaar MS, Garling A, Kern M: Fifteen-year outcome of posterior all-ceramic inlay-retained fixed dental prostheses. J Dent 2019; 103174

2. Beier US, Kapferer I, Dumfahrt H: Clinical long-term evaluation and failure characteristics of 1,335 all-ceramic restorations. Int J Prosthodont 2012; 25: 70–78

3. Belleflamme MM, Geerts SO, Louwette MM, Grenade CF, Vanheusden AJ, Mainjot AK: No post-no core approach to restore severely damaged posterior teeth: An up to 10-year retrospective study of documented endocrown cases. J Dent 2017; 63: 1–7

4. Bömicke W, Rammelsberg P, Stober T, Schmitter M: Short-Term Prospective Clinical Evaluation of Monolithic and Partially Veneered Zirconia Single Crowns. J Esthet Restor Dent 2017; 29: 22–30

5. Burke FJ, Crisp RJ, Cowan AJ, Lamb J, Thompson O, Tulloch N: Five-year clinical evaluation of zirconia-based bridges in patients in UK general dental practices. J Dent 2013; 41: 992–999

6. Chaar MS, Kern M: Five-year clinical outcome of posterior zirconia ceramic inlay-retained FDPs with a modified design. J Dent 2015; 43: 1411–1415

7. Chirumamilla G, Goldstein CE, Lawson NC: A 2-year retrospective clinical study of enamic crowns performed in a private practice setting. J Esthet Restor Dent 2016; 28: 231–237

8. Christel P, Meunier A, Heller M, Torre JP, Peille CN: Mechanical properties and short-term in-vivo evaluation of yttrium-oxide-partially-stabilized zirconia. J Biomed Mater Res 1989; 23: 45–61

9. Coldea A, Swain MV, Thiel N: Mechanical properties of polymer-infiltrated-ceramic-network materials. Dent Mater 2013; 29: 419–426

10. DGFDT, DGZMK. „Diagnostik und Behandlung von Bruxismus", Langversion. AWMF-Registernummer: 083-027, https://www.awmf.org/leitlinien/detail/ll/083–027.html, (Zugriff am: 13.07.2021) 2019;

11. DGPro, DGZMK. „Vollkeramische Kronen und Brücken", Langfassung 2.0. AWMF-Registernummer: 083–012, https://www.awmf.org/leitlinien/detail/ll/083–012.html, (Zugriff am: 13.07.2021) 2021;

12. Dhima M, Paulusova V, Carr AB, Rieck KL, Lohse C, Salinas TJ: Practice-based clinical evaluation of ceramic single crowns after at least five years. J Prosthet Dent 2014; 111: 124–130

13. Dogan S, Raigrodski AJ, Zhang H, Mancl LA: Prospective cohort clinical study assessing the 5-year survival and success of anterior maxillary zirconia-based crowns with customized zirconia copings. J Prosthet Dent 2017; 117: 226–232

14. Esquivel-Upshaw JF, Kim MJ, Hsu SM, et al.: Randomized clinical study of wear of enamel antagonists against polished monolithic zirconia crowns. J Dent 2018; 68: 19–27

15. Fages M, Raynal J, Tramini P, Cuisinier FJ, Durand JC: Chairside computer-aided design/computer-aided manufacture all-ceramic crown and endocrown restorations: A 7-Year Survival Rate Study. Int J Prosthodont 2017; 30: 556–560

16. Fradeani M, Aquilano A, Corrado M: Clinical experience with In-Ceram Spinell crowns: 5-year follow-up. Int J Periodontics Restorative Dent 2002; 22: 525–533

17. Fradeani M, D'Amelio M, Redemagni M, Corrado M: Five-year follow-up with Procera all-ceramic crowns. Quintessence Int 2005; 36: 105–113

18. Fradeani M, Redemagni M: An 11-year clinical evaluation of leucite-reinforced glass-ceramic crowns: a retrospective study. Quintessence Int 2002; 33: 503–510

19. Garling A, Sasse M, Becker MEE, Kern M: Fifteen-year outcome of three-unit fixed dental prostheses made from monolithic lithium disilicate ceramic. J Dent 2019;

20. Gehrt M, Wolfart S, Rafai N, Reich S, Edelhoff D: Clinical results of lithium-disilicate crowns after up to 9 years of ser-

vice. Clin Oral Investig 2013; 17: 275–284

21. Güncü MB, Cakan U, Muhtarogullari M, Canay S: Zirconia-based crowns up to 5 years in function: a retrospective clinical study and evaluation of prosthetic restorations and failures. Int J Prosthodont 2015; 28: 152–157

22. Güth JF, Stawarczyk B, Edelhoff D, Liebermann A: Zirconia and its novel compositions: What do clinicians need to know? Quintessence Int 2019; 50: 512–520

23. Habibi Y, Dawid MT, Waldecker M, Rammelsberg P, Bömicke W: Three-year clinical performance of monolithic and partially veneered zirconia ceramic fixed partial dentures. J Esthet Restor Dent 2020; 32: 395–402

24. Harder S, Wolfart S, Eschbach S, Kern M: Eight-year outcome of posterior inlay-retained all-ceramic fixed dental prostheses. J Dent 2010; 38: 875–881

25. Höland W, Schweiger M, Frank M, Rheinberger V: A comparison of the microstructure and properties of the IPS Empress 2 and the IPS Empress glass-ceramics. J Biomed Mater Res 2000; 53: 297–303

26. Ichim I, Li Q, Li W, Swain MV, Kieser J: Modelling of fracture behaviour in biomaterials. Biomaterials 2007; 28: 1317–1326

27. Ioannidis A, Bindl A: Clinical prospective evaluation of zirconia-based three-unit posterior fixed dental prostheses: Up-to ten-year results. J Dent 2016; 47: 80–85

28. Jordan AR, Micheelis W (Hrsg). Fünfte Deutsche Mundgesundheitsstudie (DMS V). Köln: Deutscher Zahnärzte Verlag DƒV, 2016

29. Keough BE, Kay HB, Sager RD, Keen E: Clinical performance of scientifically designed, hot isostatic-pressed (HIP'd) zirconia cores in a bilayered all-ceramic system. Compend Contin Educ Dent 2011; 32: 58–68

30. Kern M: Misserfolge vermeiden – adäquate Retentions- und Widerstandsform von Brückenpfeilern. Quintessenz 2011; 62: 1017–1023

31. Kern M, Passia N, Sasse M, Yazigi C: Ten-year outcome of zirconia ceramic cantilever resin-bonded fixed dental prostheses and the influence of the reasons for missing incisors. J Dent 2017; 65: 51–55

32. Kern M, Sasse M, Wolfart S: Ten-year outcome of three-unit fixed dental prostheses made from monolithic lithium disilicate ceramic. J Am Dent Assoc 2012; 143: 234–240

33. Kerschbaum T, Faber FJ, Noll FJ, et al.: Komplikationen von Cercon-Restaurationen in den ersten fünf Jahren. Dtsch Zahnärztl Z 2009; 64: 81–89

34. Kokubo Y, Sakurai S, Tsumita M, Ogawa T, Fukushima S: Clinical evaluation of Procera AllCeram crowns in Japanese patients: results after 5 years. Journal of oral rehabilitation 2009; 36: 786–791

35. Kokubo Y, Tsumita M, Sakurai S, Suzuki Y, Tokiniwa Y, Fukushima S: Five-year clinical evaluation of In-Ceram crowns fabricated using GN-I (CAD/CAM) system. Journal of oral rehabilitation 2011; 38: 601–607

36. Lauvahutanon S, Takahashi H, Shiozawa M, et al.: Mechanical properties of composite resin blocks for CAD/CAM: Dent Mater J 2014; 33: 705–710

37. Lops D, Mosca D, Casentini P, Ghisolfi M, Romeo E: Prognosis of zirconia ceramic fixed partial dentures: a 7-year prospective study. Int J Prosthodont 2012; 25: 21–23

38. Mainjot AK, Dupont NM, Oudkerk JC, Dewael TY, Sadoun MJ: From artisanal to cad-cam blocks: state of the art of indirect composites. J Dent Res 2016; 95: 487–495

39. Makarouna M, Ullmann K, Lazarek K, Boening KW: Six-year clinical performance of lithium disilicate fixed partial dentures. Int J Prosthodont 2011; 24: 204–206

40. Malament KA, Natto ZS, Thompson V, Rekow D, Eckert S, Weber HP: Ten-year survival of pressed, acid-etched e.max lithium disilicate monolithic and bilayered complete-coverage restorations: Performance and outcomes as a function of tooth position and age. J Prosthet Dent 2019; 121: 782–790

41. Marquardt P, Strub JR: Survival rates of IPS empress 2 all-ceramic crowns and fixed partial dentures: results of a 5-year prospective clinical study. Quintessence Int 2006; 37: 253–259

42. McLean JW: Evolution of dental ceramics in the twentieth century. J Prosthet Dent 2001; 85: 61–66

43. Molin MK, Karlsson SL: Five-year clinical prospective evaluation of zirconia-based Denzir 3-unit FPDs. Int J Prosthodont 2008; 21: 223–227

44. Monaco C, Caldari M, Scotti R: Clinical evaluation of 1,132 zirconia-based single crowns: a retrospective cohort study from the AIOP clinical research group. Int J Prosthodont 2013; 26: 435–442

45. Monaco C, Caldari M, Scotti R, Group ACR: Clinical evaluation of 1,132 zirconia-based single crowns: a retrospective cohort study from the AIOP clinical research group. Int J Prosthodont 2013; 26: 435–442

46. Monaco C, Llukacej A, Baldissara P, Arena A, Scotti R: Zirconia-based versus metal-based single crowns veneered with overpressing ceramic for restoration of posterior endodontically treated teeth: 5-year results of a randomized controlled clinical study. J Dent 2017; 65: 56–63

47. Mourshed B SA, Alfagih , Samran A, Abdulrab S, Kern M: Anterior cantilever resin-bonded fixed dental prostheses: a review of the literature. J Prosthodont 2018;

48. Nejatidanesh F, Moradpoor H, Savabi O: Clinical outcomes of zirconia-based implant- and tooth-supported single crowns. Clin Oral Investig 2016; 20: 169–178

49. Odman P, Andersson B: Procera AllCeram crowns followed for 5 to 10.5 years: a prospective clinical study. Int J Prosthodont 2001; 14: 504–509

50. Örtorp A, Kihl ML, Carlsson GE: A 5-year retrospective study of survival of zirconia single crowns fitted in a private clinical setting. J Dent 2012; 40: 527–530

51. Otto T, Mormann WH: Clinical performance of chairside CAD/CAM feldspathic ceramic posterior shoulder crowns and endocrowns up to 12 years. Int J Comput Dent 2015; 18: 147–161

52. Otto T, Mörmann WH: Clinical performance of chairside CAD/CAM feldspathic ceramic posterior shoulder crowns and endocrowns up to 12 years. Int J Comput Dent 2015; 18: 147–161

53. Passia N, Chaar MS, Kern M: Outcome of posterior fixed dental prostheses made from veneered zirconia over an observation period of up to 13 years. J Dent 2019; 86: 126–129

54. Passia N, Stampf S, Strub JR: Five-year results of a prospective randomised controlled clinical trial of posterior computer-aided design-computer-aided manufacturing ZrSiO4 -ceramic crowns. J Oral Rehabil 2013; 40: 609–617

55. Piconi C, Maccauro G: Zirconia as a ceramic biomaterial. Biomaterials 1999; 20: 1–25

56. Pihlaja J, Napankangas R, Raustia A: Outcome of zirconia partial fixed dental prostheses made by predoctoral dental students: A clinical retrospective study after 3 to 7 years of clinical service. J Prosthet Dent 2016; 116: 40–46

57. Pjetursson BE, Tan, WC, Tan, K, Brägger, U, Zwahlen, M, Lang, NP: A systematic review of the survival and complication rates of resin-bonded bridges after an observation period of at least 5 years. Clin Oral Implants Res 19 2008; 131–141

58. Raigrodski AJ, Yu A, Chiche GJ, Hochstedler JL, Mancl LA, Mohamed SE: Clinical efficacy of veneered zirconium dioxide-based posterior partial fixed dental

prostheses: five-year results. J Prosthet Dent 2012; 108: 214–222

59. Rathmann F, Bomicke W, Rammelsberg P, Ohlmann B: Veneered zirconia inlay-retained fixed dental prostheses: 10-Year results from a prospective clinical study. J Dent 2017; 64: 68–72

60. Rauch A, Reich S, Dalchau L, Schierz O: Clinical survival of chair-side generated monolithic lithium disilicate crowns:10-year results. Clin Oral Investig 2018; 22: 1763–1769

61. Rinke S, Gersdorff N, Lange K, Roediger M: Prospective evaluation of zirconia posterior fixed partial dentures: 7-year clinical results. Int J Prosthodont 2013; 26: 164–171

62. Rinke S, Kramer K, Burgers R, Roediger M: A practice-based clinical evaluation of the survival and success of metal-ceramic and zirconia molar crowns: 5-year results. J Oral Rehabil 2016; 43: 136–144

63. Rinke S, Wehle J, Schulz X, Burgers R, Rodiger M: Prospective evaluation of posterior fixed zirconia dental prostheses: 10-Year Clinical Results. Int J Prosthodont 2018; 31: 35–42

64. Sailer I, Balmer M, Husler J, Hämmerle CHF, Kanel S, Thoma DS: 10-year randomized trial (RCT) of zirconia-ceramic and metal-ceramic fixed dental prostheses. J Dent 2018; 76: 32–39

65. Sailer I, Bonani T, Brodbeck U, Hämmerle CH: Retrospective clinical study of single-retainer cantilever anterior and posterior glass-ceramic resin-bonded fixed dental prostheses at a mean follow-up of 6 years. Int J Prosthodont 2013; 26: 443–450

66. Sailer I, Strasding M, Valente NA, Zwahlen M, Liu S, Pjetursson BE: A systematic review of the survival and complication rates of zirconia-ceramic and metal-ceramic multiple-unit fixed dental prostheses. Clin Oral Implants Res 2018; 29 Suppl 16: 184–198

67. Sasse M, Kern M: CAD/CAM single retainer zirconia-ceramic resin-bonded fixed dental prostheses: clinical outcome after 5 years. Int J Comput Dent 2013; 16: 109–118

68. Sax C, Hämmerle CH, Sailer I: 10-year clinical outcomes of fixed dental prostheses with zirconia frameworks. Int J Comput Dent 2011; 14: 183–202

69. Schmitt J, Goellner M, Lohbauer U, Wichmann M, Reich S: Zirconia posterior fixed partial dentures: 5-year clinical results of a prospective clinical trial. Int J Prosthodont 2012; 25: 585–589

70. Schmitter M, Boemicke W, Stober T: Bruxism in prospective studies of veneered zirconia restorations-a systematic review. Int J Prosthodont 2014; 27: 127–133

71. Schmitter M, Mussotter K, Rammelsberg P, Gabbert O, Ohlmann B: Clinical performance of long-span zirconia frameworks for fixed dental prostheses: 5-year results. Journal of oral rehabilitation 2012; 39: 552–557

72. Seghi RR, Daher T, Caputo A: Relative flexural strength of dental restorative ceramics. Dent Mater 1990; 6: 181–184

73. Seghi RR, Denry IL, Rosenstiel SF: Relative fracture toughness and hardness of new dental ceramics. J Prosthet Dent 1995; 74: 145–150

74. Simeone P, Gracis S: Eleven-Year Retrospective Survival Study of 275 Veneered Lithium Disilicate Single Crowns. Int J Periodontics Restorative Dent 2015; 35: 685–694

75. Sola-Ruiz MF, Agustin-Panadero R, Fons-Font A, Labaig-Rueda C: A prospective evaluation of zirconia anterior partial fixed dental prostheses: clinical results after seven years. J Prosthet Dent 2015; 113: 578–584

76. Sola-Ruiz MF, Lagos-Flores E, Roman-Rodriguez JL, Highsmith Jdel R, Fons-Font A, Granell-Ruiz M: Survival rates of a lithium disilicate-based core ceramic for three-unit esthetic fixed partial dentures: a 10-year prospective study. Int J Prosthodont 2013; 26: 175–180

77. Sorrentino R, De Simone G, Tete S, Russo S, Zarone F: Five-year prospective clinical study of posterior three-unit zirconia-based fixed dental prostheses. Clin Oral Investig 2012; 16: 977–985

78. Sorrentino R, Galasso L, Tetè S, De Simone G, Zarone F: Clinical evaluation of 209 all-ceramic single crowns cemented on natural and implant-supported abutments with different luting agents: a 6-year retrospective study. Clin Implant Dent Relat Res 2012; 14: 184–197

79. Spitznagel FA, Scholz KJ, Vach K, Gierthmuehlen PC: Monolithic polymer-infiltrated ceramic network CAD/CAM single crowns: three-year mid-term results of a prospective clinical study. Int J Prosthodont 2020; 33: 160–168

80. Steeger B: Survival analysis and clinical follow-up examination of all-ceramic single crowns. Int J Comput Dent 2010; 13: 101–119

81. Stober T, Heuschmid N, Zellweger G, Rousson V, Rues S, Heintze SD: Comparability of clinical wear measurements by optical 3D laser scanning in two different centers. Dent Mater 2014; 30: 499–506

82. Strub JR, Stiffler S, Schärer P: Causes of failure following oral rehabilitation: biological versus technical factors. Quintessence Int 1988; 19: 215–222

83. Teichmann M, Göckler F, Weber V, Yildirim M, Wolfart S, Edelhoff D: Ten-year survival and complication rates of lithium-disilicate (Empress 2) tooth-supported crowns, implant-supported crowns, and fixed dental prostheses. J Dent 2017; 56: 65–77

84. Toman M, Toksavul S: Clinical evaluation of 121 lithium disilicate all-ceramic crowns up to 9 years. Quintessence Int 2015; 46: 189–197

85. Valenti M, Valenti A: Retrospective survival analysis of 261 lithium disilicate crowns in a private general practice. Quintessence Int 2009; 40: 573–579

86. Valenti M, Valenti A: Retrospective survival analysis of 110 lithium disilicate crowns with feather-edge marginal preparation. Int J Esthet Dent 2015; 10: 246–257

87. Vigolo P, Mutinelli S: Evaluation of zirconium-oxide-based ceramic single-unit posterior fixed dental prostheses (FDPs) generated with two CAD/CAM systems compared to porcelain-fused-to-metal single-unit posterior FDPs: a 5-year clinical prospective study. J Prosthodont 2012; 21: 265–269

88. Walton TR: A 10-year longitudinal study of fixed prosthodontics: clinical characteristics and outcome of single-unit metal-ceramic crowns. Int J Prosthodont 1999; 12: 519–526

89. Wendler M, Belli R, Petschelt A, et al.: Chairside CAD/CAM materials. Part 2: Flexural strength testing. Dent Mater 2017; 33: 99–109

90. Wolleb K, Sailer I, Thoma A, Menghini G, Hämmerle CH: Clinical and radiographic evaluation of patients receiving both tooth- and implant-supported prosthodontic treatment after 5 years of function. Int J Prosthodont 2012; 25: 252–259

91. Zhang Y, Lawn BR: Novel Zirconia Materials in Dentistry. J Dent Res 2018; 97: 140–147.

Photo: UKD

Corresponding author:
DR ANNIKA JERG
Department of Prosthodontics, Medical Faculty and University Hospital Düsseldorf, Heinrich-Heine-University, 40225 Düsseldorf, Germany
annika.jerg@med.uni-duesseldorf.de

Kathinka Offer, Sabine Linsen, Philipp Kohorst

Retrospective study of glass-ceramic single tooth restorations after up to 15 years

Introduction: Glass-ceramic single-tooth restorations count among the standard treatments in dental practice at present owing to their good esthetics, biocompatibility and survival rates. The aim of this study was to investigate the occurrence of various long-term complications based on data collected from a general dental practice.

Material and methods: A retrospective analysis of 1132 posterior single-tooth restorations made of Empress 2 and IPS e.max ceramic from 251 patients was performed. The restorations were placed between 2000 and 2015 by a single dental practitioner in a private general dental practice. The minimum observation period was 2 years. The patient records were examined for the following complications: fracture, root canal treatment, periodontal complications, occlusal adjustment procedures to correct occlusal interferences, postoperative hypersensitivity, secondary caries and decementation. The statistical analysis was based on the ceramic used (Empress 2 and IPS e.max) and the type of restoration (inlay, partial crown, or crown).

Results: Twelve of the 769 Empress 2 and 3 of the 363 IPS e.max restorations failed due to bulk fracture. There was no significant difference between the materials ($p = 0.411$). Crowns displayed a significantly higher fracture rate compared to inlays or partial crowns ($p = 0.02$ and $p = 0.04$), irrespective of material. Empress 2 restorations showed a significantly higher incidence (3.6 %) of premature occlusal contacts requiring adjustment compared to IPS e.max restorations (1.4 %) ($p = 0.037$). No correlation between occlusal adjustment procedures and fracture was observed ($p = 0.426$). Empress 2 crowns had a significantly higher probability of decementation ($p < 0.001$) compared to Empress 2 inlays or partial crowns. Teeth with IPS e.max restorations exhibited significantly more postoperative hypersensitivitity ($p < 0.001$) and required root canal treatment significantly more frequently ($p = 0.041$) than teeth with Empress 2 restorations. Periodontal complications occurred significantly more often in teeth with IPS e.max crowns than in teeth with IPS e.max inlays or partial crowns ($p = 0.005$). The incidence of secondary carious lesions was not significantly higher neither with respect to material nor type of restoration.

Conclusion: Both glass-ceramic materials are suitable for everyday use in dentistry; IPS e.max and Empress 2 restorations demonstrated good long-term clinical results and an acceptable amount of complications. The most common complications were postoperative hypersensitivity, fractures and periodontal complications. The number of complications was higher for crowns than for inlays or partial crowns.

Keywords: glass-ceramic; IPS e.max; Empress 2; single-tooth restorations; complications; long-term performance; retrospective; fracture rate

Polyclinic for Dental Prosthetics, Propaedeutics and Materials Science, Rheinische Friedrich-Wilhelms-Universität Bonn: Kathinka Offer, PD Dr. MSc. Sabine Linsen
Private practice for dentistry: Dr. Alexander Offer, Lilienthaler Heerstraße 261, 28357 Bremen: Prof. Dr. Philipp Kohorst
Translation from German: Cristian Miron
Citation: Offer K, Linsen S, Kohorst P: Retrospective study of glass-ceramic single tooth restorations after up to 15 years. Dtsch Zahnärztl Z Int 2021; 3: 257–265
Peer-reviewed article: submitted: 28.07.2020, revised version accepted: 30.11.2020
DOI.org/10.3238/dzz-int.2021.0032

1 Introduction

All-ceramic single-tooth restorations constitute an integral part of the dental treatment spectrum nowadays due to their good esthetics, biocompatibility and very good long-term results in terms of survival probability [2, 14, 21, 38, 41].

The greatest difficulty lies in their lack of mechanical stability and strength, which is determined, in particular, by the pronounced brittle fracture properties and the low tensile load-bearing capacity [35]. The resulting fractures and chipping present a major challenge for dental practice and research. Yet, great progress has been made in this field in recent decades. With the introduction of leucite and lithium disilicate ceramics Empress 1 and 2 at the end of the 1980s and early 1990s, the slow crack growth that is especially problematic for glass-ceramics was significantly reduced through the incorporation of mechanically more stable leucite and lithium disilicate crystals.

Although great improvements have been made with regard to the parameters that influence glass-ceramic materials such as material properties and luting materials, a large number of studies do not include other factors which are involved in the failure process and incidence of complications [12, 13, 31, 36]. It is known that, in addition to the material's inherent properties, dentogenic, patient-related and dentist-dependent factors also influence the survival probability of restorations [5, 22].

The aim of this retrospective study was to provide a practice-oriented analysis of the complications of glass-ceramic inlays, partial crowns and crowns made of Empress 2 and IPS e.max Press. With this in mind, the incidence of the complications fracture, decementation, endodontic treatment, postoperative hypersensitivity, periodontal complications, occlusal interferences requiring occlusal adjustment procedures and secondary caries was investigated in relation to the type of restoration (inlay, partial crown, and crown) and material (Empress 2, IPS e.max). The null hypothesis stated that the incidence of complications was stochastically independent of the type of restoration (inlay, partial crown, crown) and material (Empress 2, IPS e.max).

2 Material und methods

2.1 Study design and complications

The patient collective was selected from a private general dental practice. All glass-ceramic single-tooth restorations made of Empress 2 or IPS e.max which were placed between 01.01.2000 and 31.12.2015 were included in the study. Data was collected retrospectively based on the procedure's respective billing code. The inclusion criteria were: glass-ceramic single-tooth restorations in the posterior region (first premolar to third molar) made of the materials Empress 2 and IPS e.max from Ivoclar Vivadent, a minimum observation period of 2 years and a minimum patient age of 18 years.

The complications fracture, decementation, postoperative hypersensitivity, secondary caries, premature occlusal contacts, periodontal complications and root canal treatment were evaluated according to a yes/no format. Together with the complications, the material (IPS e.max and Empress 2) and the type of restoration (inlay, partial crown and crown) were also recorded.

The complications were defined as follows: fracture was defined as chipping of the ceramic which lead to the restoration's failure and the subsequent need for a new one. Chipping that did not require restoration renewal was not included in the study.

Root canal treatments after a restoration was placed were recorded regardless of whether restoration renewal was needed. Periodontal complications comprised of all the situations in which the patient required systematic periodontal therapy in the area of the restored tooth after the restoration's placement. Premature contacts requiring adjustment and postoperative hypersensitivity were recorded up to 4 months after the restoration was placed.

The recording of secondary caries ensued when it resulted in restorative treatment in the form of a new filling or restoration.

The study project was registered by the Ethics Committee of the University of Bonn under number 274/20 and approved on 16.06.2020.

2.2 Treatment procedure

The patients stemmed from a private general dental practice and all the treatments were performed by a single dentist. Likewise, all the restorations were fabricated in the practice's dental laboratory by a single dental technician.

Before the start of treatment, the dental examination and periodontal status were recorded and a clinical functional analysis was completed for each patient. Depending on the diagnosis, conservative treatment, professional tooth cleaning/periodontal treatment or functional therapy were performed as part of the pretreatment. After, prosthetic treatment ensued.

The preparation design of inlays and partial crowns took the size of the defect into account and made use of rounded inner edges. Cusps were included in the preparation design of partial crowns and rounded, 1 mm wide shoulder margins were prepared. The marginal design of crowns was also performed as a 1 mm wide circular chamfer preparation with rounded inner edges. Tooth substance removal was between 1.5–2 mm occlusally and 1.5 mm circumferentially and the taper was 6–10°. The preparation margin was positioned supragingivally, equigingivally or subgingivally according to the clinical conditions. Special attention was given to the preparation of rounded edges.

A one-step double mix impression using the double cord technique was made with the polyether material Impregum 3M ESPE. Occlusal registration was performed either in the maximum intercuspidation or in the centric condylar position based on the requirements of each individual case. The restorations were fabricated in the Ivocalr EP 600 Combi press furnace according to the manufacturer's instructions. The enamel was etched with 30–40 % phosphoric acid and the restoration was conditioned for 20 seconds with 5 % hydrofluoric acid before its cementation. The ce-

mentation was made using the Syntac Classic adhesive system (Ivoclar Vivadent) and one of the following dual-curing adhesive luting materials: Variolink 2 (Ivoclar Vivadent), RelyX (3M Espe), G-Cem (GC), Panavia SA (Kuraray), Tetric Evo Flow (Ivoclar Vivadent), Filtek Supreme (3M Espe) or PermaCem (DMG). When the circumstances permitted, rubber dam was used during the cementation procedure. In cases where occlusal adjustments were needed, this was performed – after cementation – with a diamond-coated round or football bur. Subsequently, the restorations were polished intraorally with diamond grit ceramic polishers (Komet, Germany).

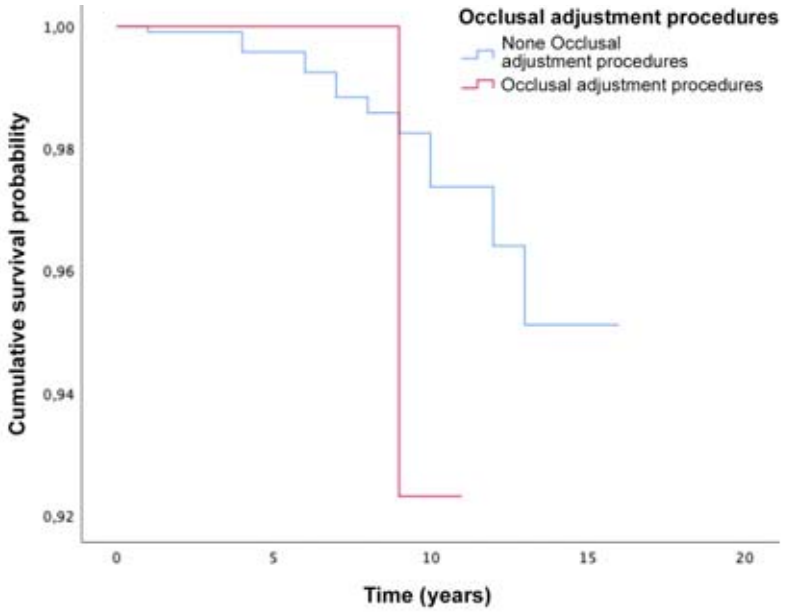
2.3 Statistical analysis

The statistical analysis and graphical representations were made using the SPSS software for Windows, version 24.0 (SPSS Inc., U.S.A.). The data were evaluated descriptively and expressed as percentages and absolute numbers in order to express the incidence of complications comparatively between the restoration types (inlay, partial crown, crown) and between the materials (Empress 2, IPS e.max). The chi-square test and the Fisher exact test, in the case of low numbers, were applied in order to compare the incidence of complications among the restoration types (inlay, partial crown, crown) and materials (Empress 2, IPS e.max). The effect of adjustment procedures on the survival of glass-ceramic single-tooth restorations was investigated using Kaplan-Meier analyzes and the significance was determined using the log rank test. Differences between the groups were determined as being significant at $p < 0.05$.

3 Results

A total of 1132 restorations from 251 patients were evaluated. The mean observation period was 6.5 ± 3.3 years.

Overall, 363 restorations were made of IPS e.max and 769 of Empress 2. The mean ages of patients with Empress 2 and IPS e.max restorations were 46.6 (± 10.31) and 51.46 (± 12.29) years, respectively. The number of restorations placed in male and female patients was 455 and 677, respectively. The total of 1132 restorations consisted of 331 crowns (Empress 2 n = 215, IPS e.max n = 116), 487 partial crowns (Empress 2 n = 315, IPS e.max n = 172) and 314 inlays (Empress 2 n = 239, IPS e.max n = 75). Before the start of treatment, 1065 vital and 65 avital abutment teeth were present. A list of the data is found in Tables 1 and 2.



Tab. 1 and 2, Fig. 1: Kathinka Offer

Figure 1 Kaplan-Meier diagram showing the survival probability of restorations which did and did not require occlusal adjustment procedures due to premature contacts.

3.1 Fracture

Over the course of the observation period, 15 restorations failed due to fracture. Twelve (1.6 %) were made of Empress 2 and 3 (0.8 %) of IPS e.max. The fracture rate between Empress 2 and IPS e.max restorations is not significantly different ($p = 0.411$).

With respect to the type of restoration, 10 crowns (3 IPS e.max, 7 Empress 2) and 5 partial crowns made of Empress 2 fractured. Crowns made of Empress 2 and IPS e.max fractured significantly more frequently ($p < 0.04$ and $p < 0.02$) than partial crowns and inlays made of the same material (see Tables 1 and 2).

Furthermore, only one out of 33 restorations needing adjustment due to premature contacts fractured. This corresponds to a survival probability of 97.0 % in the group with adjustment procedures and 98.7 % in the group without. The p value of 0.426 indicates that the differences between the two groups are not significant (Fig. 1).

3.2 Root canal treatment

Altogether, 18 (1.6 %) of the 1132 teeth underwent root canal treatment after the restoration was placed. Eight (0.7 %) restorations were made of IPS e.max and 10 (0.9 %) of Empress 2. The difference between the materials is statistically significant at $p = 0.041$ (see Tables 1 and 2).

In comparing the different types of restorations, no significant difference with regard to the need for root canal treatment existed, neither for Empress 2 nor for IPS e.max.

3.3 Decementation

Nine of the 769 Empress 2 (1.2 %) and none of the 363 IPS e.max restorations became loose. No statistically significant difference between the materials existed (see Tables 1 and 2).

In terms of the type of restoration, only crowns made of Empress 2 became loose ($p < 0.001$).

3.4 Periodontal complications

Periodontal deterioration subsequent to restoration placement with the

	all restorations		IPS e.max		IPS e.max		P
	n	%	n	%	n	%	
Number of treatments	1132	100	769	67.9	363	32.1	–
Fractures							
Total	15	1.3	12	1.6	3	0.8	0.411
Crowns	10	0.9	7	3.3	3	2.6	–
Partial crowns	5	0.4	5	1.6	0	0	–
Inlays	0	0	0	0	0	0	–
Root canal treatment							
Total	18	1.6	8	**0.7**	10	0.9	**0.041**
Crowns	8	0.7	3	1.4	**5**	4.3	
Partial crowns	8	0.7	5	1.6	3	1.7	
Inlays	2	0.2	0	0	2	2.7	
Decementation							
Total	9	0.8	9	**0.8**	0	0	**0.041**
Crowns	9	1.2	9	4.2	**0**	0	
Partial crowns	0	0	0	0	0	0	
Inlays	0	0	0	0	0	0	
Periodontal complications							
Total	13	1.1	8	0.7	5	0.4	0.766
Crowns	6	0.5	1	0.5	**5**	4.3	
Partial crowns	0	0	5	1.6	0	0	
Inlays	0	0	2	0.8	0	0	
Secondary caries							
Total	8	0.7	8	0.7	0	0	0.061
Crowns	2	0.1	2	0.9	**0**	0	
Partial crowns	3	0.3	3	1	0	0	
Inlays	3	0.3	3	1.3	0	0	
Occlusal adjustment procedures							
Total	33	2.9	28	**2.4**	5	0.5	**0.037**
Crowns	13	1.1	8	3.7	**4**	3.6	
Partial crowns	16	1.4	15	4.8	1	0.6	
Inlays	5	0.4	5	2.1	0	0	
Postoperative hypersensitivity							
Total	72	6.3	23	**2**	49	4,3	**0.000**
Crowns	39	3.4	7	3.3	**32**	27,6	
Partial crowns	24	2.1	10	3.2	14	8,1	
Inlays	9	0.8	6	2.5	3	4	

Table 1 Complications consisting of fractures, root canal treatment, decementation, periodontal complications, secondary caries, occlusal interferences and postoperative hypersensitivity for Empress 2– und IPS e.max restorations

need for systematic periodontal therapy was observed for 8 out of 769 and 5 out of 363 teeth with Empress 2 and IPS e.max restorations, respectively. No statistically significant correlation between the material ($p = 0.766$) and periodontal deterioration was seen.

In the case of IPS e.max restorations, crowns showed periodontal complications significantly more frequently ($p = 0.005$) than partial crowns or inlays made of the same material (see Tables 1 and 2).

3.5 Secondary caries

Eight of the 769 Empress 2 and none of the 363 IPS e.max restorations developed secondary carious lesions during the observation period.

Neither the comparison of materials nor the comparison of restoration type showed statistically significant differences ($p > 0.061$) (see Tables 1 and 2).

3.6 Premature contacts requiring adjustment

Empress 2 restorations required occlusal adjustment procedures significantly more frequently ($p = 0.037$) than IPS e.max restorations (28 of 769 versus 5 of 363).

The type of restoration, on the other hand, had no significant influence on the need for occlusal adjustment procedures (see Tables 1 and 2).

3.7 Postoperative hypersensitivity

Postoperative hypersensitivity occurred significantly more frequently in teeth with IPS e.max restorations ($p = 0.001$) compared to teeth with Empress 2 restorations (49 out of 363 restorations versus 23 out of 769 restorations).

IPS e.max crowns exhibited a higher risk of postoperative hypersensitivity than partial crowns and inlays in this study (see Tables 1 and 2).

4 Discussion

The incidence of complications was evaluated as a function of material and the type of restoration. The results can serve as a decision-making aid for the dental practitioner when

selecting the material and type of restoration.

4.1 Fracture

There were no significant differences between the fracture rates of Empress 2 and IPS e.max restorations in this study. However, significant differences between the restoration types were seen ($p < 0.04$). Crowns made of both materials showed a significantly higher probability of fracturing than inlays or partial crowns. A possible explanation for this may be the increase in defects per area; with increasing restoration size, the microcracks and pores responsible for failure also increase [35].

Furthermore, in vitro studies have shown that partial crown preparations have a very favorable stress distribution pattern under load [7]. This may, in combination with the predominantly enamel limited preparation [34], explain the significantly better fracture rates of partial crowns and inlays.

In addition to the inherent defects of the material, sufficient material layer thickness and the adhesive bond, the correct preparation also has a fundamental influence on the clinical success of glass-ceramic restorations [11, 19, 33]. Due to the retrospective study approach, it is not possible to track the material layer thicknesses and whether the preparation was appropriate for the material. An incorrect, possibly too angular, preparation and/or too little tooth substance removal for glass-ceramic crowns may also explain their increased fracture rates compared to partial crowns and inlays.

The results found in literature correspond to those presented here with respect to the fracture rates of IPS e.max restorations [23], while the results on the fracture rates of Empress 2 restorations are significantly lower in this study compared to those reported in literature [12]. For example, a 10-year study on the survival probability of IPS e.max restorations by Malament et al [23] showed a fracture rate of 0.3 %. However, in addition to single-tooth restorations, the study included three-unit bridges and one-wing adhesive bridges. No differentiation was made between the various types of restorations in terms of the fracture rates.

	Crown		Partial crown		Inlay		P
	n	%	n	%	n	%	
Total fractures	10	0.9	5	0.4	0	0.0	
Empress 2	7	3.3	5	1.6	0	0.0	**0.020**
IPS e.max	3	2.6	0	0.0	0	0.0	**0.040**
Total root canal treatments	8	0.7	8	0.7	2	0.2	
Empress 2	3	1.4	5	1.6	0	0.0	0.158
IPS e.max	5	4.3	3	1.7	2	2.7	0.042
Total decementations	9	0.8	0	0.0	0	0.0	
Empress 2	9	4.2	0	0.0	0	0.0	**0.000**
IPS e.max	0	0.0	0	0.0	0	0.0	–
Total periodontal complications	6	0.5	5	0.4	2	0.2	
Empress 2	1	0.5	5	1.6	2	0.8	0.427
IPS e.max	5	4.3	0	0.0	0	0.0	**0.005**
Total secondary caries	2	0.1	3	0.3	3	0.3	
Empress 2	2	0.9	3	1.0	3	1.3	0.925
IPS e.max	0	0.0	0	0.0	0	0.0	–
Total occlusal adjustment procedures	13	1.1	16	1.4	5	0.4	
Empress 2	8	3.7	15	4.8	5	2.1	0.251
IPS e.max	4	3.6	1	0.6	0	0.0	0.064
Total postoperative hypersensitivity	39	3.4	24	2.1	9	0.8	
Empress 2	7	3.3	10	3.2	6	2.5	0.870
IPS e.max	32	27.6	14	8.1	3	4.0	**0.000**

Table 2 Separation of complications between the restoration types for Empress 2 and IPS e.max.

The fracture rate of 0.8 % of Empress 2 restorations was significantly lower in the present study compared to the values between 1 % and 15.6 % reported in literature [8, 10]. However, it should be taken into account that the study design varied considerably. In a prospective 12-year study by Frankenberger et al [12], for example, a fracture rate of 12.5 % for Empress 2 inlays and onlays was seen. However, in their study, in addition to the fracture rates, the influence of different luting materials was investigated as well. It was found that restorations fractured more frequently when they were cemented with a light-curing adhesive luting material compared to a dual-curing luting material [12]. However, the fracture rates were determined independently of the luting material [12]. Since only dual-curing luting materials were used in the current study, this may be a possible reason for the better results. In a retrospective 11-year long study by Fradeani et al. [10] on the fracture rate of leucite-reinforced glass-ceramic crowns, a fracture rate of 15.6 % was reported for posterior restorations over the study period. Only crowns were investigated in their study. However, the results in this current study suggest that significant differences exist in the survival rates of different single-tooth restorations (inlays, partial crowns and crowns). Since this study determined that crowns fractured significantly more frequently than partial crowns or inlays, and Fradeani et al. [10] exclusively investigated crowns, this may explain the considerably lower values.

A meta-analysis by El-Mowafy et al. [8] investigating the survival probabilities and long-term clinical performance of Empress 2 restorations showed slightly lower survival rates for Empress 2 crowns (ranging from 92 % to 99 % after 3–3.5 years) compared to inlays and partial crowns (ranging from 91 % and 96 % after 4.5–7 years). These results correspond most closely to the results of the current study.

In literature, it has been reported that, in addition to the degradation (or corrosion) of silicate ceramic materials, adjustment procedures with the associated development of new crack nuclei are often responsible for the failure of a restoration [19]. However, literature on this topic is inconsistent: in a study by Ludovichetti et al. [20], no negative influence on the fracture strength of IPS e.max and Lava Ultimate (Vita Enamic) samples was found after grinding and polishing procedures, even after mechanical aging. In contrast, Schmitter at al. [29] demonstrated a reduced fracture strength (560.6 ± 233.3 N vs. 535.5 ± 128.0 N) for zirconia crowns in the anterior region after incisal adjustment procedures. This could not be confirmed in the current study. The survival probability of restorations that underwent adjustment procedures was 97.0 % compared to 98.7 % for restorations that did not undergo adjustment procedures ($p = 0.426$). Further clinical studies on this topic are needed to draw definitive conclusions.

The results of current study suggest that there is a relationship between fracture rate and restoration size. Since crowns fractured significantly more frequently than inlays and partial crowns, it is advisable to perform a risk analysis prior to prosthetic planning and material selection in order to be able to set the course for a more durable restoration in good time. Since the reasons for a fracture cannot be understood in detail retrospectively, the adherence to material thickness is once again emphasized.

4.2 Root canal treatment

In this study, root canal treatment was performed significantly more frequently ($p = 0.045$) on teeth with IPS e.max restorations than on teeth with Empress 2 restorations. No significant difference was determined when differentiating between the restoration types inlay, partial crown and crown.

A limited amount of literature exists regarding endodontic complications for glass-ceramic restorations. Failure rates due to endodontic complications are reported to be between 0.2 % and 2 % for IPS e.max restorations [17, 30] and these are thus slightly lower than in current study.

The degree of tooth substance destruction and the proximity of the defect to the dental pulp before restoration were not recorded in this study. Since a correlation to the restorative material is rather improbable, it would be useful for future studies to consider other influencing factors such as the extent of the defect, the indications for restorative treatment, the etching and adhesive system used and the luting material.

Despite significant differences between the materials, both Empress 2 as well as IPS e.max restorations display a low risk of requiring root canal retreatment.

4.3 Decementation

In the present study, 9 Empress 2 crowns and no IPS e.max restorations became loose. The difference between the types of restorations was statistically significant for Empress 2 restorations ($p = 0.001$), whereas there was no significant difference with respect to material. Crowns made of Empress 2 loosened significantly more frequently than partial crowns or inlays made of the same material.

In literature, few comparable studies exist so far. In a study by van den Breemer et al. [41], 2 of 73 (1.2 %) lithium disilicate restorations became loose over a period of 15 years. Thereby, loosening was the third most frequent failure cause after fracture and secondary caries. In a systematic literature review, van den Breemer et al. [40] also showed that the bond strength of glass-ceramic restorations is significantly lower when the bond is purely in dentin compared to the bond in enamel. Since the dentin wound is greatest when crowns are prepared and it further decreases from the partial crown to the inlay, this may potentially explain the higher decementation rates of Empress 2 crowns that were determined in this study.

Likewise, the decementation of Empress 2 restorations has only been discussed in a few studies to date. This may be due to the fact that the loosening of a restoration – with its possible recementation – was not considered a failure, and thus, remains unspecified in a large number of studies.

Teichmann et al. [37] reported a decementation rate of 6.9 % after 10 years in a prospective study on the complication and survival rates of lithium disilicate restorations. These results are considerably higher than the values of 1.1 % after 15 years determined in the present study. In their study, Teichmann et al. included both conventionally and adhesively cemented restorations. In the current study, dual-curing adhesive luting materials were exclusively used to cement the restorations. This may be a reason for the different results. Studies have demonstrated repeatedly that the shear, tensile and bond strengths of adhesive luting materials are significantly superior to those of conventional luting cements [3, 4, 24, 26, 40]. Given that the decementation rates of conventionally cemented glass-ceramic restorations differ significantly from adhesively luted cements [25], this can explain the different results.

The results of the current study suggest that, apart from the influences described in literature regarding surface conditioning, the luting material applied and the remaining tooth substance [25, 40], the shape of the restoration can also have an influence on decementation of the restoration.

However, since the position of the crown margin (supragingival or subgingival) was not recorded in this study, and given that its position has a significant influence on the likelihood of absolute moisture control, and consequently on the possibility of errors occuring during adhesive cementation, it is advisable to integrate it in future studies.

4.4 Periodontal problems

Five of 111 teeth which were treated with IPS e.max crowns showed periodontal complications. Teeth with partial crowns and inlays made of the same material were not affected. Crowns therefore exhibited periodontal complications significantly more frequently ($p = 0.005$) than inlays or partial crowns.

No significant differences existed between the Empress 2 and IPS e.max materials.

These results are concordant with recent literature. Ababnaeh et al. [1] determined that Class II restorations exhibited the highest probing depths as well as the highest plaque index, Class V restorations showed the highest attachment loss and crowns displayed the highest gingival index in the area of the restoration margin. All of these restorations have the preparation margin localized near the cementoenamel junction, free gingiva and subgingival area in common.

In the present study, other influencing factors such as the applied luting material, the adhesive system, the position and integrity of the crown margin and the plaque index were not included. Due to the retrospective design, these factors could not be obtained from the patient records with the necessary consistency and methodology which is required for clear evaluation. In the current study, only the need for systemic periodontal therapy was considered a criterion for periodontal complications. Further information such as the PSI, the plaque index, the attachment level or the position and integrity of the crown margin can be helpful in order to include and differentially consider the multifactorial influences that can lead to damage.

Nevertheless, ceramic restorations generally show a high biocompatibility and are described as being very well tolerated periodontally [1]. This is reflected in this study. Hence, periodontal treatment was required in only 1 % of all Empress 2 and 1.4 % of all IPS e.max restorations.

4.5 Secondary caries

Secondary caries required treatment in 1 % of all Empress 2 restorations and in none of the IPS e.max restorations. They therefore represent the rarest complication. No statistically significant differences existed between the materials, Empress 2 and IPS e.max, and the various types of restorations.

In various meta-analyses [8, 39], secondary caries represented the most frequent complication of glass-ceramic restorations.

Since sociodemographic factors are known to influence caries prevalence [6, 16], they may possibly represent a cause for the discrepancy in results between literature and this study. The patient collective in this study stemmed from a private dental practice; a more sociodemographically diverse patient collective would be desirable in future studies. In addition, the collection of patients' plaque indices and oral hygiene habits could potentially provide information about patient-related influencing factors.

4.6 Premature occlusal contacts

There was a significant difference ($p = 0.037$) with regard to the premature occlusal contacts between Empress 2 (3.6 %) and IPS e.max (1.4 %). No differences existed with regard to the type of restoration.

In literature, the occlusal fit of IPS e.max restorations is rated as being very good [9]. Comparable studies for Empress 2 restorations are not available in literature.

It should be taken into account that the number of placed restorations has an influence on the need for premature occlusal contacts to be adjusted. In patients that required occlusal adjustments, an average of 8.8 restorations were placed, whereas in patients without the need for occlusal adjustments, an average of only 4.5 were placed. This indicates that, in addition to the material, the number of restorations can also have an influence on occlusal interferences.

An increased number of restorations is also indicated in the case of changes in the occlusion. The sagittal and vertical rehabilitation of the occlusion comprises of many intermediary steps which can contribute to cumulative occlusal defects. In this study, all patients who received glass-ceramic restorations due to a change in occlusion were pretreated with a splint. Bite registration was performed in the centric condylar position.

The causes for the reconstruction of the occlusion and tooth hard substance can be manifold; parafunctional abrasions and erosions represent a widespread indication. This should be considered given that patients, who already showed parafunctions before therapy, can also react more sensitively to disturbances in occlusion after.

In this study, 3 of the 7 patients with occlusal dysfunctions displayed signs of severe bruxism in the form of myopathy as well as occlusal wear facets not concordant with age, while another 2 of 7 patients displayed moderate bruxism. Only 2 patients showed no symptoms which would be indicative of this parafunction. Thus, in further studies, the connection between the indication for rehabilitation, the number of restorations and bruxism activity together with the occurrence of posttherapeutic occlusal interferences should also be investigated.

As discussed previously under the heading "4.1. Fracture" in this study, increased fracture rates could not be determined after occlusal adjustments were performed.

4.7 Postoperative hypersensitivity

Postoperative hypersensitivity was observed significantly more frequently for IPS e.max restorations, especially crowns, than for Empress 2 restorations.

In literature, similar results have been reported for Empress 2 restorations. In 2010, Van Dijeken et al. [42] described that persistent hypersensitivity lasted 2–4 weeks for 3 % of the restorations, while Krämer et al. [18] reported hypersensitivity in 4 % of Empress 2 inlays up to 4 years after placement. The restorations were adhesively cemented in both studies (Van Dijeken: three 3-step etch-and-rinse systems and two 2-step etch-and-rinse systems, Krämer: EBS Multi/Compolute [3M Espe] and Syntac/Variolink II).

Comparable studies are lacking for lithium disilicate ceramics. In a prospective 10-year study on three-unit bridges with a lithium disilicate ceramic framework, Solá-Ruiz et al. [32] determined reversible postoperative hypersensitivity in 14.3 % of cases. This would be consistent with the result obtained in this study.

Even if various causes for postoperative hypersensitivity exist, such as increased thermal conductivity of the restorative material or preparation close to the pulp, postoperative hypersensitivity is currently believed to be primarily associated with adhesive restorations or adhesive restorative materials.

The reason for this – according to the hydrodynamic theory of Brännström and Aström [15] – has to do with intratubular fluid movements which arise due to small gaps between dentin and composite. If the dentinal canals are not completely sealed by the applied bonding system, dentinal fluid can leak out and cause irritation of the A-δ fibers during occlusal loading.

The use of dual-curing adhesives and phosphoric acid is considered another risk factor for the occurrence of postoperative hypersensitivity [15]. However, since both phosphoric acid as well as dual-curing adhesive luting materials (Variolink II [Ivoclar Vivadent], G-Cem [GC], RelyX [3M Espe], Tetric EvoFlow [Ivoclar Vivadent], Panavia SA Cement [Kuraray], G-Cem [GC], Filtek Supreme [3M Espe], PermaCem [DMG]) were used to condition the tooth hard substance and cement the restorations for both types of restorative materials (IPS e.max and Empress 2) in this study, the significant differences with regard to hypersensitivity cannot be explained by this.

The cause for the differences between the types of restorations could be related to the size and depth of the dentin wound. Though the size of the dentin wound is greatest for crown preparation, it decreases progressively from partial crown to inlay. This is also reflected in the determined values.

Nevertheless, this does not explain the difference between the materials because no significant differences for Empress 2 restorations with 3.3 % of crowns, 3.2 % of partial crowns and 2.5 % of inlays were determined.

Since both Empress 2 and IPS e.max restorations showed very good results in terms of their biocompatibility, chemical resistance, cytotoxicity and sensitization potential in various studies [2, 27, 28], the toxicological properties inherent in the material appear unlikely to be the cause of postoperative hypersensitivity. There were no significant differences between Empress 2 and IPS e.max restorations with regard to the distribution of restoration type, patient age or gender; this may explain the increased hypersensitivity of IPS e.max restorations.

Due to the retrospective study design, it is no longer possible to thoroughly trace the differences with regard to the etching and adhesive systems applied. This may be a possible reason for the increased hypersensitivity of IPS e.max restorations.

5 Conclusions

In summary, both Empress 2 and IPS e.max restorations showed good clinical results and an acceptable level of complications in daily dental practice. Occlusal adjustments do not appear to increase the fracture rate of glass-ceramic restorations. Decreased bonding to the enamel surface, however, increases the risk of fracture, decementation, periodontal complications and postoperative hypersensitivity.

Postoperative hypersensitivity, root canal treatment and periodontal complications occurred significantly more frequently for IPS e.max than for Empress 2 restorations in this study.

Given the proven, very good toxicological properties of both ceramics [2, 27, 28], the results of this study suggest that further studies on glass-ceramic restorations should be conducted to explore factors which were not investigated in this study. These studies should consider factors such as the close proximity to the pulp and subgingival localization of restorations, as well as, the etching and adhesive systems or luting materials applied.

Conflict of interest

The authors declare that there is no conflict of interest as defined by the guidelines of the International Committee of Medical Journal Editors.

References

1. Ababnaeh KT, Al-Omari M, Alawneh TN: The effect of dental restoration type and material on periodontal health. Oral Health Prev Dent 2011; 9: 395–403

2. Anusavice KJ: Degradability of dental ceramics. Adv Dent Res 1992; 6: 82–89

3. Behr M, Rosentritt M, Mangelkramer M, Handel G: The influence of different cements on the fracture resistance and marginal adaptation of all-ceramic and fiber-reinforced crowns. Int J Prosthodont 2003; 16: 538–542

4. Burke FJ: The effect of variations in bonding procedure on fracture resistance of dentin-bonded all-ceramic crowns. Quintessence Int 1995; 26: 293–300

5. Burke FJ, Lucarotti P: Ten-year outcome of crowns placed within the General Dental Services in England and Wales. J Dent 2009; 37: 12–24

6. Dutra LDC, Barbos Neves ET, Morais de Lima LC et al.: Degree of family cohesion and social class are associated with the number of cavitated dental caries in adolescents. Braz Oral Res 2020; Apr 17;34:e037. doi: 10.1590/1807–3107 bor-2020.vol34.0037. eCollection 2020.

7. Edelhoff D, Beuer F, Güth JF: Vollkeramische Präparation und Farbnahme. https://www.zwp-online.info/fachgebiete/implantologie/grundlagen/vollkeramische-restauration-praeparation-und-farbnahme, 2013 (letzter Zugriff am 26.07.2020)

8. El-Mowafy O; Brochu JF: Longevity and clinical performance of IPS-Empress ceramic restorations – a literature review. J Can Dent Assoc 2002; 68: 233–237

9. Esqivel-Upshaw J, William R, Oliveira E, Yang M, Clark AE, Anusavice K: Randomized, controlled clinical trial of bilayer ceramic and metal-ceramic crown performance. J Prosthodont 2012; 33: 166–173

10. Fradeani M, Redemagni M: An 11-year clinical evaluation of leucite-reinforced glass-ceramic crowns: a retrospective study. Quintessence Int 2002; 33: 503–510

11. Frankenberger R, Möring G, Blunck U, Hajtó J, Pröbster L, Ahlers O: Präparationsregeln für Keramikinlays und -teilkronen unter besonderer Berücksichtigung der CAD/CAM Technologie.

Bayrisches Zahnärzteblatt 2008; https://www.bzb-online.de/apr08/45_51.pdf (letzter Zugriff am 26.07.2020)

12. Frankenberger R, Taschner M, Garcia-Godoy F, Petschelt A, Krämer N: Leucite-reinforced glass ceramic inlays and onlays after 12 years. J Adhes Dent 2008; 10: 393–398

13. Gehrt M, Wolfart S, Rafai N, Reich S, Edelhoff D: Clinical results of lithium-disilicate crowns after up to 9 years of service. Clin Oral Invest 2013; 17: 275–284

14. Guess PC, Selz CF, Steinhart YN, Stampf S, Strub JR: Prospective clinical split-mouth study of pressed and CAD/CAM all-ceramic partial-coverage restorations: 7-year results. Int J Prosthodont 2013; 26: 21–25

15. Haller B: Die postoperative Hypersensibilität. zm online 2009; 6

16. Krämer N, Lohbauer U, Frankenberger R: Adhesive luting of indirect restorations. Am J Dent 2000; 13: 60D–76D

17. Krämer N, Frankenberger R: Clinical performance of bonded leucite-reinforced glass ceramic inlays and onlays after eight years. Dent Mater 2005; 21: 262–271

18. Krämer N, Ebert J, Petschelt A, Frankenberger R: Ceramic inlays bonded with two adhesives after 4 years. Dent Mater 2006; 22: 13–21

19. Lohbauer U: Belastbarkeit von Keramiken – Ursachen für Frakturverluste. 2012; https://www.zwp-online.info/fachgebiete/zahntechnik/werkstoffe/belastbarkeit-von-keramiken-ursachen-fuer-fraktur verluste (letzter Zugriff am 26.07.2020)

20. Ludovichetti FS, Trindade FZ, Abado GL, Pezzato L: Effect of grinding and polishing on the roughness and fracture resistance of cemented CAD-CAM monolithic materials submitted to mechanical aging. J Prosthet Dent 2019; 121: 866.e1–866.e8

21. Mackert JR: Side-effects of dental ceramics. Adv Dent Res 1992; 6: 90–93

22. Malament KA, Socaransky SS: Survival of Dicor glass-ceramic dental restorations over 20 years: Part IV. The effects of combinations of variables. Int J Prosthodont 2010; 23: 134–140

23. Malament K, Natto ZS, Thompson V, Rekow D, Eckert S, Weber HP: Ten-year survival of pressed, acid-etched e.max lithium disilicate monolithic and bilayered complete-coverage restorations: Performance and outcomes as a function of tooth position an age. J Prosthet Dent 2019; 121: 782–790

24. Michelini FS, Belser UC, Sherrer S, De Rijk WG: Tensile bond strength of gold and porcelain inlays to extracted teeth using three cements. Int J Prosthodont 1995; 8: 324–331

25. Mobilio N, Fasiol A, Mollica F, Catapano S: Effect of different luting agents on the retention of lithium disilicate ceramic crowns. Materials (Basel, Switzerland) 2015; 8: 1604–1611

26. Peutzfeld A, Sahafi A, Flury S: Bonding of restorative materials to dentin with various luting agents. Oper Dent 2011; 36: 266–273

27. Roulet JH: Seitenzahnversorgung mit adhäsiv befestigten Keramikinlays. Quintessenz 1989

28. Schäfer R, Kappert HF: Die chemische Löslichkeit von Dentalkeramiken. Dtsch Zahnärztl Z 1993; 48: 625–628

29. Schmitter M, Lotze G, Bömicke W, Rues S: Influence of surface treatment on the in-vitro fracture resistance of zirconia-based all-ceramic anterior crowns. Dent Mat 2015; 31:1552–1560

30. Scientific Report IPS e.max, Ivoclar Vivadent 2013; 2: 9

31. Sjögren G, Lantto R, Granberg A, Sundström BO, Tillberg: A clinical examination of leucite-reinforced glass-ceramic crowns (Empress) in general practice: A retrospective study. Int J Prosthodont 1999; 12: 122–128

32. Solá-Ruiz MF et al.: Survival rates of a lithium disilicate-based core ceramic for three-unit esthetic fixed partial dentures: A 10-year prospective study. Int J Prosthodont 2013; 26: 175–180

33. Strub JRK, Türp JC, Witkowski S, Heydecke G, Wolfart S: Präparationstechnik – Werkstoffkundliche und konstruktionsbedingte Kriterien. Curriculum Prothetik Band II. Quintessenz Verlag, Berlin 2011; S. 452

34. Strub JRK, Türp JC, Witkowski S, Heydecke G, Wolfart S: Prinzipien bei Veneers und Teilkronen. Curriculum Prothetik Bank II. Quintessenz Verlag Berlin 2011; S. 677

35. Strub JRK, Türp JC, Witkowski S, Heydecke G, Wolfart S: Curriculum Prothetik Band II. Quintessenz Verlag, Berlin 2011

36. Taskonak B, Sertgöz A: Two-year clinical evaluation of lithia-disilicate-based all-ceramic crowns and fixed partial dentures. Dent Mat 2006; 22: 1008–1013

37. Teichmann M, Göckler F, Weber V, Yildrim M, Wolfart S, Edelhoff D: Ten-year survival and complication rates of lithium-disilicate (Empress 2) tooth-supported crowns, implant-supported crowns, and fixed dental protheses. J Dent 2016; 56: 65–77

38. Valenti M, Valenti A: Retrospective survival analysis of 110 lithium disilicate crowns with feather-edge marginal preparation. Int J Esthet Dent 2015; 10: 246–257

39. Vagropoulou GI, Klifopoulou GL, Vlahou SG, Hirayama H, Michalakis K: Complications and survival rates of inlays and onlays vs. complete coverage restorations: A systematic review and analysis of studies. J Oral Rehabil 2018; 45: 903–920

40. Van den Breemer CR, Gresnight MM, Cune MS: Cementation of glass ceramic posterior restorations: a systematic review. Biomed Res Int 2015; 2015: 148954. doi: 10.1155/2015/148954

41. van den Breemer CR, Vinkenborg C, van Pelt H, Edelhoff D, Cune MS: The clinical performance of monolithic lithium disilicate posterior restorations after 5, 10 and 15 years: A retrospective case series. Int J Prosthodont 2017; 30: 62–65

42. van Dijken JW, Hasselrot L: A prospective 15-year evaluation of extensive dentin-enamel-bonded pressed ceramic coverages. Dent Mat 2010; 26: 929–939

Photo: Kathinka Offer

KATHINKA OFFER
Polyclinic for Dental Prosthetics, Propaedeutics and Materials Science, Rheinische Friedrich-Wilhelms University Bonn
Welschnonnenstr. 17, 53111 Bonn
kathinka@dr-offer.de

Carolin Rehnisch, Oskar Feußner, Isabell Klima, Nadja Rabkow, Lilith Pukas, Alexandra Sapalidis, Emilia Ehring, Lea Keuch, Stefan Watzke

Depressive symptoms in dentistry students – prevalence, risk factors and resilience factors

Introduction: Depression is a leading cause of illness-related disability worldwide. An initial peak of illness is recorded in the young adult years. Among epidemiologic studies of young people, studies of students are primarily available. The mental health of dental students has received little research attention. Many students subjectively report mental health complaints, while studies on this topic are scarce nationally and internationally. This study investigates the mental health of dental students at a medium-sized German university.

Methods: A sample of n = 153 dental students completed the Beck Depression Inventory-II to assess depressive symptoms, the NEO Five-Factor Inventory to assess the personality trait neuroticism, and a self-description and study questionnaire that included 8 risk factors, 5 study-related stress factors, and 8 resilience factors described in literature.

Results: 41,8 % of the students showed mild (18,3 %), moderate (17,0 %), or severe (6,5 %) depressive symptoms. 5 potential risk factors, 4 potential stress factors and 5 potential resilience factors were identified, which also revealed a cumulative effect: The more risk and stress factors the students indicated, the more depressive symptoms they showed. The opposite was true for the resilience factors.

Discussion: The prevalence of depressive symptoms in dental students exceeds that of both the general population and previous national and international studies of depressive symptoms in students. Neuroticism and the use of drugs and medications are potential risk factors, and excessive demands and pressure to perform are study-related stress factors. Emotional support and satisfaction with studies have a protective effect against depressive symptoms.

Conclusion: The results are of great significance not only because of the current psychological strain on dental students but also regarding their role in the health care system. Students should be informed and sensitized regarding this issue. Specific education on depression is useful to destigmatize the issue and raise awareness of the condition. University programs can also contribute to an early recognition and prevention of depressive symptoms to protect the mental health of potential future dentists.

Keywords: dentistry students; mental health; depression; depressive symptoms; prevalence; risk factors; resilience factors; prevention

University Hospital and Polyclinic for Psychiatry, Psychotherapy and Psychosomatics, University Hospital Halle (Saale), Martin-Luther-Universität Halle-Wittenberg, Julius-Kühn-Str. 7, 06112 Halle/Saale: Carolin Rehnisch, Oskar Feußner, Isabell Klima, Nadja Rabkow, Lilith Pukas, Alexandra Sapalidis, Emilia Ehring, Lea Keuch, Stefan Watzke
Translation from German: Yasmin Schmidt-Park
Citation: Rehnisch C, Feußner O, Klima I, Rabkow N, Pukas L, Sapalidis A, Ehring E, Keuch L, Watzke S. Depressive symptoms in dentistry students – prevalence, risk factors and resilience factors. Dtsch Zahnärztl Z Int 2021; 3: 266–275
Peer-reviewed article: submitted: 23.10.2020, revised version accepted: 15.07.2021
DOI.org/10.3238/dzz-int.2021.0033

1 Introduction

According to the Global Burden of Disease Study of the WHO, depression is one of the main causes of disease-related disability worldwide [45], has an alarmingly high share of the global burden of disease and ranks eleventh among the causes of disability-adjusted life years (DALYs) [38]. Mental disorders account for 22.7 % of DALYs worldwide, while caries, periodontitis and edentulism account for only 6.1 % [45]. The point prevalence for depression in the German general population is 8.1 % (women: 10.2 %, men: 6.1 %) [10]. Lifetime prevalence is reported to be 19 %, and women are affected twice as often as men (25 %, 12 %) [46].

A first peak of the disease is recorded in the young adult years. For both sexes, the prevalence of relevant depressive symptoms of disturbance value is highest among 18- to 29-year-olds (women: 11.8 %, men: 8.0 %); it decreases with increasing age [10].

Among epidemiologic studies of young people, studies for students are most available. In 2016, Rotenstein and colleagues reported a prevalence of depressive symptoms of 27.2 % in a meta-analysis of 183 papers and n = 122,356 medical students from 43 countries [40]. An ongoing study (Pukas et al., in preparation) investigated the psychological distress of medical students at a medium-sized German university. Of the students surveyed, 19 % had a BDI-II sum score indicative of mild, moderate, or severe symptomatology. Two other papers from this group by Kindt et al. [32] and Rabkow et al. [39] show a point prevalence of 28 % and 33.4 %, respectively, for undergraduate students in psychology and law, respectively, indicating at least mild depressive symptomatology.

Certain risk factors have been confirmed for the multifactorial genesis of depressive disorders. A distinction is made between biological and psychosocial factors.

Biological factors include genetic predisposition [34], female gender [10], and neurobiological and hormonal changes [3, 9]. Psychosocial factors include low socioeconomic status [11], growing up in the former East Germany [43], critical life events [31], financial worries [1], use of alcohol, drugs, or medication to calm down or enhance performance [6, 25, 33], and the personality trait neuroticism [15, 36].

Factors explicitly associated with students are exam and performance pressure [1], competitive behavior among students [19], experience of being overwhelmed, a subjectively perceived heavy workload and time pressure [29, 37], and loneliness [12, 39].

While the mental health of medical students is increasingly becoming the focus of public attention, both internationally and nationally, the mental health of dental students has received little attention to date. However, there is little difference in the risk- and study-related stressors of the two courses, suggesting similar symptomatology.

A national study from Giessen with n = 101 dental students compared to n = 237 medical students concluded that one in five dental students showed mild to moderate depressiveness according to BDI-II. Medical students were more satisfied with their studies than dental students despite heavier workloads [28].

In addition to the pressure of suffering during studies, the consequences for the later profession must also be taken into account. Physicians suffering from depressive symptoms have been shown to commit more professional errors than non-depressed colleagues [17, 18]. Negative effects can also be suspected in dentists. Höfel [24] and Heinze [22] emphasize the comparatively greater risk among dentists of suffering from mental and psychosomatic illnesses than among medical colleagues. Dentists are exposed to high time and organizational pressure due to bureaucratic requirements of health insurance companies and quality management. In contrast to other medical professions, dentists are often confronted with very anxious patients whose psychological problems become particularly apparent in stressful situations. In addition, precise treatment in the very small area of the oral cavity under unhealthy posture and close patient contact is very strenuous [22, 24].

Finally, there are only insufficient empirical findings on the burden of depressive symptoms and relevant risk factors for dental students in Germany.

The aim of the present study is to assess the prevalence of depressive symptoms among students and to identify risk and resilience factors associated with depressive symptoms.

2 Materials and methods

2.1 Sample

The data of the present study was collected in the summer semester 2019 from April to May at the Martin Luther University Halle-Wittenberg. Of n = 188 enrolled dental students in all semesters, n = 153 (81.4 %) participated in the survey. The sample included n = 33 (21.6 %) second semester students, n = 23 (15 %) fourth semester students, n = 37 (24.2 %) sixth semester students, n = 30 (19.6) eighth semester students, and n = 30 (19.6 %) tenth semester students. The mean age of the students was 23.7 years (range: 18 to 38 years). Among the subjects, n = 96 (62.7 %) were female and 57 (37.3 %) were male students.

2.2 Study design

The depressiveness of dental students was quantitatively assessed in the form of a cross-sectional analysis. Risk, stress, and resilience factors were additionally surveyed. Self-report questionnaires were used for the survey. These were taken from a study on depressive symptoms in medical and law students, respectively [39], and were adapted only with regard to some formulations (e.g., “dental studies” instead of “medical studies”). The responsible ethics committee voted positively for the study (Vote No. 2017-138, Amendment 03/19).

Students were informed about the aim of the study, the voluntary and anonymous nature of participation, and the possibility to withdraw from the survey at any time. Data were kept confidential at all times during the study in accordance with the Data Protection Act.

Risk factors	Stress factors	Resilience factors
Family history of mental illness	Experienced competition between students	Use of relaxation techniques
Growing up in NBL	Perceived increased time pressure	Satisfaction with studies
low socioeconomic status of family of origin	Experience of being overwhelmed	Significance of religion
Separation of parents/loss of parent in childhood	Pressure to perform	Healthy diet
Financial burden	Loneliness	Actively making music
Alcohol abuse		Actively participating in sports
Drug/medication abuse		Experienced emotional support
Neuroticism		Sufficient social contacts

Table 1 Presentation of risk, stress and resilience factors extracted from the literature with reference to depressiveness

2.3 Measuring instruments

The self-description and study questionnaire included 68 questions on sociodemographic variables and possible risk, stress, and resilience factors related to depression. The first part of the questionnaire contained questions on self-description, and the second part contained questions on study. A total of 13 risk factors, including 5 study-related stress factors and 8 resilience factors, were recorded using this questionnaire, which are shown in Table 1 and described in more detail below.

Risk factors

The risk factor familial burden of mental illness is present if a first- or second-degree family member (sibling, parent, or grandparent) is or was undergoing treatment for a mental illness, excluding dementia. Female gender is assumed to be a risk factor if the "biological sex" item is answered "female." If students grew up in one of the 5 eastern states of Germany, the risk factor of growing up in the new states is present. Low economic status is assumed if at least one of the following response alternatives applies to both the father and the mother of the family of origin: "no school qualification", "lower secondary school" or "unskilled professional activity". The risk factor loss of a parent in childhood is present if participants indicate having lost mother or father through death or separation. Financial stress is assumed if students have "sometimes too little" or "often too little" financial resources or if participants indicate that they are "usually under a lot of financial pressure." The risk factors of alcohol consumption or use of drugs and medications are present if students consume 8 (male) or 6 (female) drinks per occasion more than once a month or if they use drugs or medications to calm down or enhance performance. The risk factor neuroticism is assessed using a separate questionnaire and explained in the corresponding section.

Stress factors

Daily stresses during studies are surveyed with the question "Are there things that make it difficult for you to be happy with your study decision?" Competition among students, time constraints, pressure to perform, excessive demands and loneliness are considered as stress factors.

Resilience factors

If students answer "Yes" to the item "Do you use specific techniques for relaxation (e.g. yoga, PMR […]), it is assumed that the resilience factor is present. Satisfaction with the studies is assumed to be present in the case of a positive response to the questions "Do you enjoy your studies?", "From today's perspective, would you decide to study dentistry again?" and "Overall, how satisfied are you with your studies?". The importance of religion counts as a resilience factor if students rate it as "extremely important" or "moderately important. The resilience factor healthy nutrition is present if the items "Do you eat regular meals?" and "Do you pay attention to healthy nutrition?" are answered positively. When answering the questions "How many hours per week do you actively exercise?" with "more than two hours per week" and "How many hours per week do you actively play music?" with "more than one hour per week," these same resilience factors are considered.

Sufficient emotional support and social contacts are taken as given when answering the items with "enough" or "more than enough".

The Beck Depression Inventory-II (BDI-II [5]) was used to assess depressive symptoms. The BDI-II is an established self-report instrument that measures the severity of depressive symptoms within the last 2 weeks. Although the BDI-II is not suitable for diagnosing depressive disorder, it is used in both clinical and healthy subjects and has reliable classification criteria [23]. Symptoms of depression are recorded based on 21 items. Each item is answered using a 4-point Likert scale, and the item values are added to a sum score (0–63 points). The psychometric parameters of the BDI-II are reliable in both clinical and non-clinical samples and show good objectivity, reliability and validity [23].

The NEO Five-Factor Inventory (NEO-FFI) is also a self-report instrument [8]. It is used to assess personality traits according to Costa and McCrae [15]. In the past, a relationship between the factor neuroticism and depression has been confirmed [36], which is why only the subscale

neuroticism from the current edition of the NEO-FFI is used in this questionnaire. Neuroticism describes the tendency to emotional lability, high stress sensitivity, anxiety and sadness, irritability, anger, rage, and easy vulnerability [20]. Correlations of neuroticism and depression are generally described as high [30, 36]. For its part, neuroticism has a strong genetic component, which in turn is associated with alterations in cortisol release, attentional and learning processes, and consequently has a strong correlation with the genetics of depressive disorders [44]. The subscale consists of 12 items, each of which is answered using 5-point Likert scales. The responses in the items are summed (after reversing the polarity of individual items) to give a total score, and the total score is divided by the item number. This results in a mean value, which can be between 0 and 4. The higher the mean, the stronger the expression of the personality trait neuroticism; a score above 2.54 represents one standard deviation above the age-related population mean. The risk factor neuroticism was assumed to be present in the present study if the individual score was above this cut-off.

2.4 Evaluation

The collected data was analyzed using the statistical software "Statistical Package for Social Sciences" (SPSS 25.0). The sociodemographic description of the total sample as well as the determination of the prevalence of depressive symptoms and the description of the total sample with regard to the BDI-II sum score were carried out using descriptive statistics and the determination of absolute and relative frequencies. The frequency of occurrence of each risk, stress, and resilience factor was also described using descriptive statistics and the determination of relative frequencies. Due to violated normal distribution assumptions in the BDI-II sum score (Kolmogorov goodness-of-fit test: $Z = 0.127$; $p < 0.001$), associations between it and the recorded risk and resilience factors were determined using Spearman rank correlation. Due to the calculation of multiple correlations in each case, the critical □-error level in each variable group was Bonferroni-corrected. Finally, to account for the intercorrelation of the included variables and to correct for multicollinearity, a multivariate linear regression model (stepwise with $p_{in} = 0.05$ and $p_{out} = 0.10$) was calculated to predict the BDI-II sum score including all univariate significantly correlating variables.

BDI-II-total score				
Semester of study	**M**	**SD**	**MD**	**Range**
2 (n = 33)	10.2	8.1	8	0–30
4 (n = 23)	11.3	7.5	10	0–30
6 (n = 37)	13.2	8.3	12	1–28
8 (n = 30)	11.8	8.2	8.5	1–32
10 (n = 30)	19.2	9.2	17.5	5–34
Total (n = 153)	**13.2**	**8.8**	**11**	**0–34**

Table 2 BDI-II total scores in semester levels

3 Results

3.1 Results of the BDI II sum score

Including all students surveyed (n = 153), the mean BDI-II sum score was M = 13.2 points (SD = 8.80). Norm scores of university students are reported by Beck and colleagues [5] and given as M = 12.6, SD = 9.9. Compared to this sample, no deviant scores are found in the collective studied here ($t = 0.801$; $p = 0.424$). However, when compared to students in other fields of study studied at the same university, deviations are found. Kindt et al. [32] reported M = 9.95 (SD = 7.34) for n = 109 students in an undergraduate psychology program and M = 8.84 (SD = 7.12) points in the BDI-II for n = 564 students in preclinical human medicine. Rabkow et al. [39] studied n = 306 law students and found a mean BDI-II score of 11.9 (SD = 8.45) points. In the present study, scores deviating from this were found in comparison to psychology students ($t = 4.53$; $p < 0.001$) and to human medicine students ($t = 6.01$; $p < 0.001$), but not to law students ($t = 1.79$; $p = 0.076$).

An elevated BDI-II sum score was recorded in n = 64 of 153 students (41.8 %) (≥14 p.), and a scale score indicative of major depression (≥ 29 points) was found in 10 (6.5 %) dental students [5].

Women and men do not differ significantly in the extent of depressive symptoms ($t = 0.771$; $p = 0.441$). However, a significant difference in symptom burden is found between included semesters ($F[df = 4] = 5.58$; $p < 0.001$; see Table 2). Post hoc individual comparisons show that this global difference is due to increased scores in the 10th FS. Students in this group differ significantly from all other semester groups in post hoc analyses (all $p < 0.04$).

The BDI II items with the most frequent elevated scores in the present sample were change in sleep behavior, fatigue, loss of energy, self-criticism, lack of concentration, and irritability. The items worthlessness, feelings of punishment, and suicidal ideation had the lowest scores. The question about suicidality was answered affirmatively by 19 (12.4 %) students, but only the phrase "I have suicidal thoughts, but I would not carry them out." (item value = 1) was used.

3.2 BDI-II sum score in relation to risk factors

Table 3 shows the bivariate correlations between BDI-II sum score

Risk factor	BDI-II- toal scores *r*	prevalence (%)
(1) family burden with mental illness	0.17	36.4
(2) grew up in NBL	0.07 n.s.	74.0
(3) low socioeconomic status	0.11 n.s.	2.7
(4) loss of parent	0,19	13,2
(5) financial burden9	0,18	26,7
(6) alcohol use	–0,04	23,3
(7) drugs/medication	0,31*	11,3
(8) neuroticism (> M + 1 SD)a	0,58*	22,9

Table 3 Bivariate correlations (Spearman rank correlation) between risk factors and BDI-II sum score, prevalences of risk factors within student group
r = Pearson correlation coefficient, total sample n = 153,
BDI-II = Beck Depression Inventory-II, NBL = new federal states.
a Neuroticism as a scale score correlates to r = 0.737*** with the BDI-II sum score.
* p_{crit} < 0,006 (Bonferroni-correction)

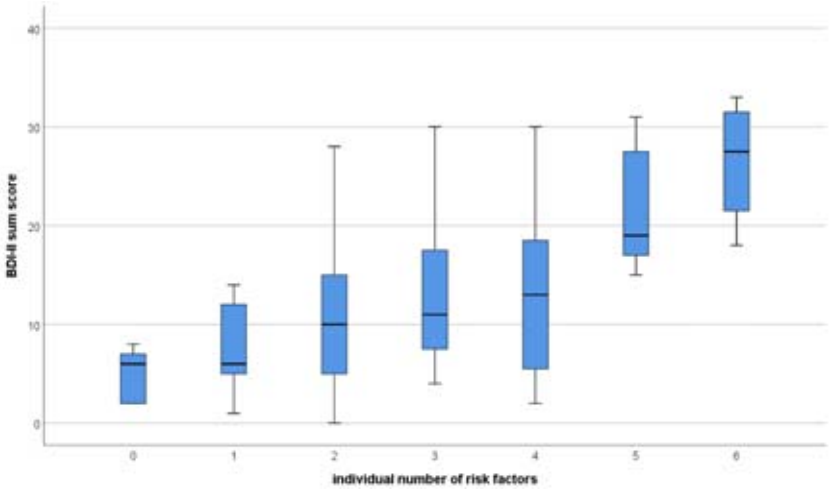


Figure 1 Distribution of BDI-II sum score for individual sums of present risk factors using boxplots (mean, interquartile range, and range)

and the risk factors as well as the relative frequencies (prevalence) of the students' risk factors.

Significant correlations emerged between the BDI-II sum score and the risk factors neuroticism and use of drugs and medications. Loss of a parent in childhood, financial worries, and family history of mental illness showed small tendential correlations, but these did not reach statistical significance after Bonferroni correction. The characteristics of female gender, growing up in the new German states, low socioeconomic status, and alcohol consumption did not prove to be significantly associated with depressiveness in the sample studied.

The individual sum of all risk factors correlates significantly with the BDI-II sum score (r = 0.39; p < 0.001) (see Figure 1).

A stepwise linear regression model including all significantly correlating variables clarifies a total of 59 % of the variance in the individual BDI-II sum score; neuroticism (R^2 = 0.57) and drug use remain as significant predictors in the model. The variance inflation factor (VIF) of the included predictors was 1.03; collinearity is therefore negligible.

3.3 BDI-II sum score in the context of stress factors

Table 4 shows the bivariate correlations between each study-related stress factor and the BDI-II sum score and the frequency of the stress factors.

Significant correlations emerged between the BDI-II sum score and the following 4 stress factors: Overwork, Pressure to Perform, Loneliness, and Time Pressure.

Concordant to the risk factors, the sum of study-related stress factors also correlated significantly with the BDI-II sum score (r = 0.41, p < 0.001). Accordingly, the more stress factors students report, the higher the BDI-II sum score. The relationship is illustrated in Figure 2 by boxplots showing the distribution of the BDI-II sum score for the respective number of stress factors present.

In a joint stepwise linear regression model, excessive demands and pressure to perform jointly clear up 13 % of the variance in the individual BDI-II sum score (VIF = 1.08).

3.4 BDI-II sum score in the context of resilience factors

Table 5 shows the bivariate correlations between the individual resilience factors and the BDI-II sum score and the respective prevalence of the resilience factors.

Significant correlations were found between the BDI-II sum score and the following 5 resilience factors: sufficient emotional support, satisfaction with studies, sports, social contacts, and healthy diet. The factors use of relaxation techniques, importance of religion, and active music making were not found to be significantly associated with depressiveness in the sample studied

The sum of resilience factors correlated significantly negatively with the BDI-II sum score (r = –0.50; p < 0.001, see Figure 3).

A stepwise linear regression model explains 37 % of the variance of the individual BDI-II sum score. The largest proportion of explained variance comes from emotional sup-

Stress factor	BDI-II-total score *r*	Prevalence (%)
(1) Competition among students	0.13	7.8
(2) Time pressure	0.16	66.0
(3) Excessive demands	0.34*	34.6
(4) Pressure to perform	0.28*	64.7
(5) Loneliness	0.20*	13.7

Table 4 Bivariate correlations (Spearman rank correlation) between stress factors and BDI-II sum score, prevalences of stress factors within student groups
Notes: r = Spearman rank correlation coefficient, total sample n = 153, BDI-II = Beck Depression Inventory-II
* p < 0,01 (Bonferroni-correction)

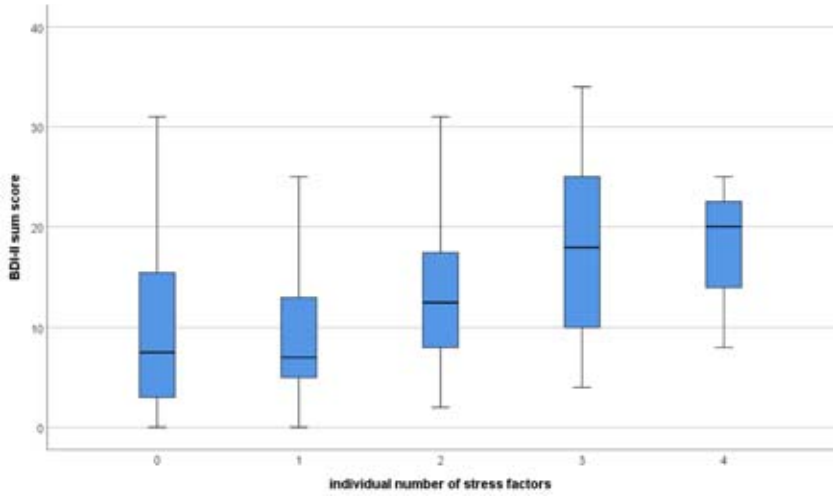


Figure 2 Distribution of BDI-II sum score for individual sums of present risk factors using boxplots (mean, interquartile range, and range)

port (R^2 = 0.23), followed by satisfaction with studies (additional R^2 = 0.10) and sports (additional R^2 = 0.04, all VIF < 1.1).

A final model including the significant predictors of the individual variable groups yields a joint variance explanation of R^2 = 0.66 (all VIF = 1). The most significant predictors of depressive symptoms in the model are neuroticism, emotional support, sports, satisfaction with studies, pressure to perform, and excessive demands.

4 Discussion

Depressive symptoms are common in the general population [10]. This study investigated the previously poorly studied mental health situation of dental students in their individual semesters. Risk factors, stress factors, and resilience factors associated with depressive symptoms were also collected. Consequently, the aim of the study was to assess the prevalence of depressive symptoms in dental students and to clarify the influence of risk and resilience factors on students' mental health. Last but not least, this should contribute to the development of preventive measures against mental overload for future dentists.

4.1 Discussion of the results of the BDI-II

The average BDI-II sum score only minimally exceeds the norm values of university students reported by Beck et al. [4], but it shows to be elevated in comparison to the scores of psychology and human medicine students in the preclinical section collected by Kindt et al. [32] and Rabkow et al. [39], as well as to the scores for law students determined by Rabkow et al.

The prevalence of at least mild depressive symptoms is 41.8 %, which is higher than that of 18- to 29-year-olds from the general population (women: 11.8 %, men: 8.0 %) [10]. Furthermore, the prevalence exceeds the findings of Rotenstein et al. (27.2 %), Jurkat et al. (20 %), Pukas et al. (19 %), Kindt et al. (28 %), and Rabkow et al. (33.4 %) [28, 32, 39, 40], thus underscoring the greater average burden of dental students.

However, the survey contains only data that emerges from the students' self-assessment. These self-reported depressive symptoms cannot be equated with a sound clinical diagnosis made by professional staff.

Nevertheless, the BDI-II is the gold standard for assessing the severity of depressive symptoms. The psychometric scores are reliable in both clinical and nonclinical samples and have good objectivity, reliability, and validity [23].

4.2 Discussion of results on risk factors, stress factors, and resilience factors

Risk- and study-related stress factors were assessed using self-description questionnaires. Neuroticism, use of drugs and medication, loss of a parent in childhood, financial worries, and family history correlate significantly. Of the study-related stress factors, overwork, pressure to perform, loneliness, and time pressure correlate significantly with depressiveness. The BDI-II sum score is higher the more risk or stress factors the students have.

Risk factors

The risk factor neuroticism shows the greatest correlation with the BDI-II sum score. On the one hand, emotionally unstable individuals are at increased risk for depressive symptoms [36], on the other hand, depressive states influence the self-assessment of the trait neuroticism [21]. The second strongest correlation is found for the risk factor use of

Resilience factor	BDI-II- toal score *r*	Prevalence (%)
(1) Use of relaxation techniques	–0.02	26.3
(2) Satisfaction in studies	–0.41*	74.8
(3) Importance of religion	–0.02	20.7
(4) healthy nutrition	–0.23*	54.9
(5) active music making	0.02	21.4
(6) sports	–0.27*	70.0
(7) emotional support	–0.44*	75.0
(8) social contacts	–0.25*	34.4

Table 5 Bivariate correlations (Spearman rank correlation) between resilience factors and BDI-II sum score, prevalences of resilience factors within student groups
Notes: R = Pearson correlation coefficient, total sample n = 153, BDI-II = Beck Depression Inventory-II
* p < 0,006 (Bonferroni-correction)

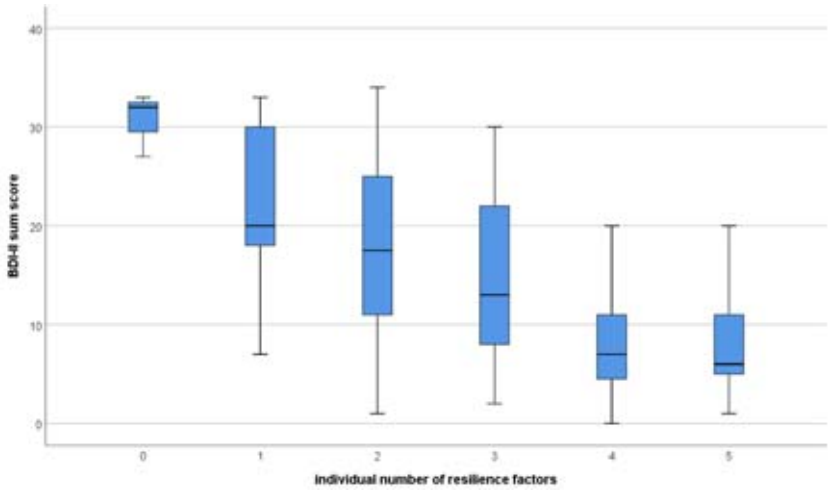


Fig. 1–3: C. Rehnisch

Figure 3 Distribution of BDI-II sum score for individual sums of available resilience factors using boxplots (mean, interquartile range, and range)

drugs and medications with a high BDI-II sum score, as also found in other works [25, 33]. A positive correlation between the prevalence of depressive episodes and the loss of a parent was postulated by Kendler [31] and can only be confirmed to a limited extent in the present study. After correction for the critical alpha error level due to multiple comparisons, this feature fails to reach statistical significance. However, follow-up studies with larger samples should continue to investigate this feature. Depressiveness represents a multifactorial phenomenon. Variables with smaller effects should therefore not be neglected, as they certainly contribute additively to the individual experience of stress.

Similarly, findings on financial strain and a positive family history of mental illness showed small effects in the present study, but failed to reach statistical significance, but have been discussed as relevant determinants of depressiveness in other studies [1, 34] No significant association was found between alcohol consumption and depressive symptoms in students in the present study. This result is not in line with the study of Boden and Fergusson, but is similar to the data of Collin et al [6, 14].

Contrary to the results of Seliger and Brähler, students who grew up in the new states of Germany do not have a higher prevalence for depressive symptoms than fellow students who grew up in the old states [43]. However, this is not very surprising in the cohort studied here, as the majority of students (74 %) come from the new federal states and thus live close to home, which presumably has a positive effect on mental health. Also, no significant relationship was found between gender and depressiveness in the present study. This result in a sample of dental students is thus not consistent with the data postulated by Busch et al. for the general population [10]. Kindt et al. and Rabkow et al. also show differences in the extent of depressive symptoms between women and men. This is all the more remarkable as these papers are studies at the same university. Thus, this risk factor appears to be less important in dental students than in the general population and in other courses of study.

Stress factors

The greatest correlation of study-related stress factors with the extent of depressive symptoms is found for the factor overwork. Such a correlation was already reported by Misra et al [37]. According to our survey, almost two-thirds of students suffer from pressure to perform. Students affected by this factor have a significantly higher BDI-II sum score, as also reported by Aselton [1]. Confirmation was also found for the relationship between loneliness [12] and depressiveness. Two thirds of all students reported suffering from time pressure. A correlation with depressiveness could be confirmed in a previous study [28], but presents itself in the present study only as a tendential correlation.

For the study-related stress factor competitive pressure, no significant relationship to depressive symptoms can be found. Consequently, the result is not consistent with the studies by Gilbert and colleagues and by Aselton [1, 19]. Whereas the latter studied American college students

and British patients diagnosed with depression, the sample studied here represents people who basically have a secure perspective from a professional point of view. The profession of dentist is associated with secure job opportunities, a high income and great social prestige.

Resilience factors

Three quarters of students report receiving sufficient emotional support from friends and family during their studies. The more support students experience, the lower their depressiveness [16]. Likewise, three quarters of students report being satisfied with their studies. Dyrbye et al. also proved this relationship in their study [16]. The third strongest relationship was found between the resilience factor sport and a low BDI-II sum score. Students who engage in several hours of active per week have a lower prevalence of depressive symptoms than fellow students to whom this resilience factor does not apply, in agreement with Babiss et al. and Johnson and Taliaferro [2, 27]. Only one-third of students reported having sufficient time for social contact. The reason for this could be the excessive demands stated by students as well as pressure to perform and lack of time. According to the results of this study, there is a negative correlation between social contacts and depressiveness, so time spent with friends and families has a positive effect on students' mental health [12]. More than half of the students reported eating a healthy diet. This relationship was already postulated by Schek and confirmed by the results of the present study [41].

No relationship was found between the importance of religion, playing a musical instrument, and practicing relaxation techniques and depressiveness in the present work. In this respect, our results do not coincide with previous studies [7, 35, 42].

It should be emphasized that it is not the factors individually, but the combination of several factors that is crucial for a high BDI-II sum score. The more risk factors and study-related stressors the study participants have, the higher their prevalence for depressive symptoms. The reverse is true for resilience factors. The more the students indicated, the lower their BDI-II sum score. Overall, neuroticism, emotional support, sports, satisfaction with studies, pressure to perform, and excessive demands proved to be significant predictors of depressiveness, largely independent of each other.

5 Limitations and outlook

The present study emphasizes the high psychological stress of dental students and highlights the relationship between selected risk and resilience factors and depressive symptoms. Correlations between the factors surveyed and depressive symptoms are evident; however, causal conclusions cannot be drawn.

It should be emphasized that the sample covers 81.4 % of the students in the study program of the university under investigation and thus promises good generalizability for the addressed population. However, students with depressive symptoms might still be over- or underrepresented in the survey, either because they stayed away from the university due to increased depressive symptoms, refused to participate for personal reasons, or – in the opposite case – the more personally relevant the study seemed, the greater their affinity to participate.

Furthermore, the present sample is limited to a medium-sized German university, which is why a generalization of the results for the entirety of all dental students is only possible to a limited extent. To strengthen the validity of the results, future studies at other universities are desirable.

It should also be noted that the present study does not involve the diagnosis of depression by psychotherapists or physicians. The questionnaires used in the survey are only self-report instruments, which is why the assessment of the severity of depressive symptoms can be falsified. Participants might have underreported or overreported scores regarding depressive symptoms [13, 26]. Nevertheless, the good convergent validity of the BDI-II should be emphasized, as there is high agreement between results of the BDI-II and a clinical diagnosis [4].

Because the data in the present cross-sectional analysis were collected at only one point in time, no conclusions can be drawn about the progression of symptoms among individual participants. Further work, for example in the form of longitudinal studies, is needed to record individual students' depressive symptoms over a longer period of time, i.e., throughout their studies and beyond.

Also limiting is the limited selection of risk, stress, and resilience factors without claiming to be exhaustive. To identify additional depressive symptom-triggering and protective factors, further research on larger samples in a more comprehensive regional context is needed in the future.

6 Conclusion

The present study provides alarming results about the mental health of dental students. More than one in three students achieved a BDI-II sum score indicative of at least mild depression.

Neuroticism and use of drugs and medications show the highest association with depressive symptoms. Overwork, pressure to perform, loneliness, and time constraints are stress factors that should be minimized in everyday study life. Resilience factors such as emotional support, satisfaction with their studies and sport, on the other hand, have a protective effect and protect students from depressive symptoms.

The findings are significant not only because of the current distress experienced by dental students, but also in terms of their potential role in the health care system. In the past, depressive symptoms in male and female physicians have been associated with a qualitative reduction in patient care. Similar findings can be hypothesized for dentists [17, 18]. Accordingly, risk-, study-related stress- and resilience factors were surveyed in order to be able to provide prevention during studies in the future. The studies show that the more risk factors students are exposed to, the more depressive symptoms they exhibit.

Students should be informed and sensitized with regard to this topic.

Education on the subject of depression makes sense in order to destigmatize and raise awareness of the disease. Seminars or lectures on the subject of coping with stress and dealing with risk and stress factors can already be held in early semesters in order to point out help options to those affected in the future in the sense of primary prevention. University programs can also contribute to early detection and secondary prevention of depressive symptoms.

Further risk factors, study-related stress factors and resilience factors should be identified in order to provide the best possible prevention and support already during studies.

Further studies should investigate the development of depressive symptoms during studies and beyond, i.e. in the everyday working life of dentists, in order to determine whether depressiveness persists after studies.

7 Acknowledgements

We thank all participants in our study.

Conflict of interest

The authors declare that there is no conflict of interest as defined by the guidelines of the International Committee of Medical Journal Editors.

References

1. Aselton P: Sources of stress and coping in American college students who have been diagnosed with depression. J Child Adolesc Psychiatr Nurs 2012; 25: 119–123

2. Babiss LA, Gangwisch JE: Sports participation as a protective factor against depression and suicidal ideation in adolescents as mediated by self-esteem and social support. J Dev Behav Pediatr 2009; 30: 376–384

3. Bale TL: Stress sensitivity and the development of affective disorders. Horm Behav 2006; 50: 529–533

4. Beck AT, Steer RA, Ball R, Ranieri W: Comparison of Beck Depression Inventories -IA and -II in psychiatric outpatients. J Pers Assess 1996; 67: 588–597

5. Beck AT, Steer RA, Brown GK: BDI-II Manual. The Psychological Corporation. Harcourt Brace & Company. San Antonio TX 1996

6. Boden JM, Fergusson DM: Alcohol and depression. Addiction 2011; 106: 906–914

7. Bonelli R, Dew RE, Koenig HG, Rosmarin DH, Vasegh S: Religious and spiritual factors in depression: review and integration of the research. Depress Res Treat 2012; 2012: 962860

8. Borkenau P, Ostendorf F: NEO-Fünf-Faktoren-Inventar nach Costa und McCrae. [Fragebogen und Testmanual]. Hogrefe, Göttingen 2007

9. Brakemeier E-L, Normann C, Berger M: Ätiopathogenese der unipolaren Depression. Neurobiologische und psychosoziale Faktoren. Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz 2008; 51: 379–391

10. Busch MA, Maske UE, Ryl L, Schlack R, Hapke U: Prävalenz von depressiver Symptomatik und diagnostizierter Depression bei Erwachsenen in Deutschland: Ergebnisse der Studie zur Gesundheit Erwachsener in Deutschland (DEGS1). Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz 2013; 56: 733–739

11. Busch M, Hapke U, Mensink GBM: Psychische Gesundheit und gesunde Lebensweise. Gesundheitsberichterstattung des Bundes kompakt 2(7). Robert Koch-Intitut, Berlin 2011

12. Cacioppo JT, Hughes ME, Waite LJ, Hawkley LC, Thisted RA: Loneliness as a specific risk factor for depressive symptoms: cross-sectional and longitudinal analyses. Psychol Aging 2006; 21: 140–151

13. Carter JD, Frampton CM, Mulder RT, Luty SE, Joyce PR: The relationship of demographic, clinical, cognitive and personality variables to the discrepancy between self and clinician rated depression. Journal of Affective Disorders 2010; 124: 202–206

14. Collin V, Toon M, O'Selmo E, Reynolds L, Whitehead P: A survey of stress, burnout and well-being in UK dentists. Br Dent J 2019; 226: 40–49

15. Costa PT, McCrae RR: Normal personality assessment in clinical practice: The NEO Personality Inventory. Psychological Assessment 1992; 4: 5–13

16. Dyrbye LN, Power DV, Massie FS et al.: Factors associated with resilience to and recovery from burnout: a prospective, multi-institutional study of US medical students. Med Educ 2010; 44: 1016–1026

17. Fahrenkopf AM, Sectish TC, Barger LK et al.: Rates of medication errors among depressed and burnt out residents: prospective cohort study. BMJ 2008; 336: 488–491

18. Garrouste-Orgeas M, Perrin M, Soufir L et al.: The Iatroref study: medical errors are associated with symptoms of depression in ICU staff but not burnout or safety culture. Intensive Care Med 2015; 41: 273–284

19. Gilbert P, McEwan K, Bellew R, Mills A, Gale C: The dark side of competition: How competitive behaviour and striving to avoid inferiority are linked to depression, anxiety, stress and self-harm. Psychol Psychother 2009; 82: 123–136

20. Goldberg LR: The structure of phenotypic personality traits. The American psychologist 1993, 48(1), 26–34.

21. Griens AMGF, Jonker K, Spinhoven P, Blom MBJ: The influence of depressive state features on trait measurement. J Affect Disord 2002; 70: 95–99

22. Heinze AD-S: Burnout bei Zahnärzten – Teil 1. https://www.zmk-aktuell.de/fachgebiete/allgemeine-zahnheilkunde/story/burnout-bei-zahnaerzten--teil-1__342.html

23. Herzberg PY, Goldschmidt S, Heinrichs N: Beck Depressions-Inventar (BDI-II). Revision. Reportpsychologie 2008: 301–302

24. Höfel L: Burnout in der Zahnarztpraxis. Teil II – Burnout-Fallen am Arbeitsplatz 2013: 50–52

25. Horwood LJ, Fergusson DM, Coffey C et al.: Cannabis and depression: an integrative data analysis of four Australasian cohorts. Drug Alcohol Depend 2012; 126: 369–378

26. Hunt M, Auriemma J, Cashaw ACA: Self-report bias and underreporting of depression on the BDI-II. J Pers Assess 2003; 80: 26–30

27. Johnson KE, Taliaferro LA: Relationships between physical activity and depressive symptoms among middle and older adolescents: a review of the research literature. J Spec Pediatr Nurs 2011; 16: 235–251

28. Jurkat H, Höfer S, Richter L, Cramer M, Vetter A: Lebensqualität, Stressbewältigung und Gesundheitsförderung bei Studierenden der Human- und Zahnmedizin. Eine Vergleichsuntersuchung. GESAMTER ARTIKEL: https://www.thieme-connect.com/products/ejournals/html/10.1055/s-0031-1280544. Dtsch Med Wochenschr 2011; 136: 1245–1250

29. Jurkat HB, Richter L, Cramer M et al.: Depressivität und Stressbewältigung bei Medizinstudierenden. Eine Vergleichsuntersuchung des 1. und 7. Fachsemesters Humanmedizin. Nervenarzt 2011; 82: 646–652

30. Jylhä P, Isometsä E: The relationship of neuroticism and extraversion to symptoms of anxiety and depression in the general population. Depress Anxiety 2006; 23: 281–289

31. Kendler KS, Karkowski LM, Prescott CA: Causal relationship between stressful life events and the onset of major depression. Am J Psychiatry 1999; 156: 837–841

32. Kindt T, Rabkow N, Pukas L et al.: A Comparison of Depressive Symptoms in Medical and Psychology Students in Germany – Associations with Potential Risk and Resilience Factors. JMP 2021: 1–13

33. Kupferschmidt H, Fattinger K: Medizinische Probleme beim Konsum illegaler Drogen. Grundlagen der Arzneimitteltherapie 2005: 274–283

34. Lieb R, Isensee B, Höfler M, Pfister H, Wittchen H-U: Parental major depression and the risk of depression and other mental disorders in offspring: a prospective-longitudinal community study. Arch Gen Psychiatry 2002; 59: 365–374

35. Lolak S, Connors GL, Sheridan MJ, Wise TN: Effects of progressive muscle relaxation training on anxiety and depression in patients enrolled in an outpatient pulmonary rehabilitation program. Psychother Psychosom 2008; 77: 119–125

36. Malouff JM, Thorsteinsson EB, Schutte NS: The Relationship Between the Five-Factor Model of Personality and Symptoms of Clinical Disorders: A Meta-Analysis. https://link.springer.com/article/10.1007/s10862–005–5384-y, 27.01.2020

37. Misra R, Castillo LG: Academic Stress Among College Students: Comparison of American and International Students. International Journal of Stress Management 2004; 11: 132–148

38. Murray CJL, Vos T, Lozano R et al.: Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. The Lancet 2012; 380: 2197–2223

39. Rabkow N, Pukas L, Sapalidis A et al.: Facing the truth – A report on the mental health situation of German law students. International Journal of Law and Psychiatry 2020; 71: 101599

40. Rotenstein LS, Ramos MA, Torre M et al.: Prevalence of Depression, Depressive Symptoms, and Suicidal Ideation Among Medical Students: A Systematic Review and Meta-Analysis. JAMA 2016; 316: 2214–2236

41. Schek A: Einfluss der Ernährung auf Depressivität und Stresstoleranz. Forum Psychotherapeutische Praxis 2003; 3: 163–172

42. Seinfeld S, Figueroa H, Ortiz-Gil J, Sanchez-Vives MV: Effects of music learning and piano practice on cognitive function, mood and quality of life in older adults. Front Psychol 2013; 4: 810

43. Seliger K, Brähler E: Psychische Gesundheit von Studierenden der Medizin. Psychotherapeut 2007; 52: 280–286

44. Smith DJ, Escott-Price V, Davies G et al.: Genome-wide analysis of over 106.000 individuals identifies 9 neuroticism-associated loci. Mol Psychiatry 2016; 21: 749–757

45. Vos T, Flaxman AD, Naghavi M et al.: Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. The Lancet 2012; 380: 2163–2196

46. Wittchen H-U et al.: Gesundheitsberichterstattung des Bundes, Heft 51: Depressive Erkrankungen. Robert Koch-Institut, Berlin 2010

Photo: S. Watzke

Corresponding author
STEFAN WATZKE
University Hospital and Polyclinic for Psychiatry, Psychotherapy and Psychosomatics, University Hospital Halle (Saale)
Martin-Luther-University Halle-Wittenberg
Julius-Kühn-Str. 7
06112 Halle/Saale
E-Mail: stefan.watzke@uk-halle.de

Carolin Sabine Harms, Vesna Husemann, Edgar Schäfer, Till Dammaschke

Removal of calcium hydroxide dressing from the root canal system using different irrigation solutions and methods

Introduction: The aim is to compare different methods for the removal of calcium hydroxide ($Ca(OH)_2$) from root canals.

Material and methods: 160 extracted human teeth were divided into 2 groups. In group 1 (n = 80), all root canals were prepared with hand instruments to ISO size 40 and in group 2 (n = 80) by rotary nickel-titanium files (Mtwo) to size 04/40. After rinsing, all root canals were filled with $Ca(OH)_2$ and the access cavity was temporized. All teeth were stored for 7 d at 37 °C and 100 % humidity. After storage, in half of the specimens of both groups (n = 40) root canal irrigation without previous instrumentation was performed. In the other half (n = 40) root canals were instrumented to working length with Hedstrom file ISO size 45. All specimens were divided in subgroups (n = 10) and rinsed with 5 ml of NaCl-solution 0.9 %, CHX 2 %, and NaOCl 2.5 % with or without ultrasonic activation, respectively. By scanning electron microscope evaluation the cleanliness of the root canal walls was scored from 1 (no $Ca(OH)_2$ visible) to 5 (pronounced layer of $Ca(OH)_2$). The data obtained were statistically evaluated by Kruskal-Wallis-test ($p < 0.05$).

Results: Ultrasonic-activated NaOCl removed significantly more $Ca(OH)_2$ than all other solutions or methods ($p < 0.05$). The instrument taper (hand instruments 2 % or NiTi files 4 %) as well as instrumentation before rinsing, had no significant influence ($p > 0.05$). For all rinsing solutions tested, the result within the respective group was independent of the localization in the root canal ($p > 0.05$).

Conclusion: Only passive ultrasonic activation was able to remove $Ca(OH)_2$ from the root canal sufficiently. Neither the taper of the instruments used nor instrumentation before rinsing had an significant influence on the removability of $Ca(OH)_2$.

Keywords: calcium hydroxide; instrument taper; passive ultrasonic irrigation (PUI); root canal irrigation; root canal dressing

Department of Periodontology and Operative Dentistry, Westphalian Wilhelms-University, Waldeyerstr. 30, 48149 Münster, Germany: Dr. med. dent. Carolin Sabine Harms, Prof. Dr. med. dent. Till Dammaschke
Private Practice, Große Bäckerstr. 18, 21335 Lüneburg, Germany: Dr. med. dent. Vesna Husemann
Central Interdisciplinary Ambulance in the School of Dentistry, Waldeyerstr. 30, 48149 Münster, Germany: Prof. Dr. med. dent. Edgar Schäfer
Citation: Harms CS, Husemann V, Schäfer E, Dammaschke T: Removal of calcium hydroxide dressing from the root canal system using different irrigation solutions and methods. Dtsch Zahnärztl Z Int 2021; 3: 276–282
Peer-reviewed article: submitted: 21.04.2021, revised version accepted: 31.05.2021
DOI.org/10.3238/dzz-int.2021.0034

Introduction

Disinfection of the root canal system after preparation and before obturation is a prerequisite for successful root canal treatment [15, 27]. Due to the complexity of the root canal system, only about 50–60 % of the canal wall surfaces are mechanically cleaned even with current rotary nickel-titanium (NiTi) instruments [25]. Therefore, under clinical conditions with a mechanical instrumentation and antibacterial irrigation it is only possible to remove microorganisms in 50–70 % of the infected root canals, depending on the irrigation protocol [2]. If a root canal is infected with microorganisms, they may survive in dentinal tubules, ramifications, accessory canals, anastomoses, apical delta etc., where they are not accessible to mechanical instrumentation or irrigation [2]. In order to remove microorganisms from an infected root canal system, the use of root canal medication is particularly indicated in non-vital teeth [15, 27]. In the past, an abundance of substances has already been proposed as a root canal medication. But until today calcium hydroxide ($Ca(OH)_2$) is a popular and commonly used, widespread root canal dressing [15, 27], introduced to dentistry for this purpose by Hermann in 1920 [13].

The effectiveness of $Ca(OH)_2$ in endodontics is mainly due to its antibacterial activity to hydrolyse the lipid moiety of bacterial lipopolysaccharides (LPS) without being cytotoxic and to dissolve soft tissue in the root canal [15, 27].

Besides many positive characteristics, $Ca(OH)_2$ has some drawbacks like being insufficiently effective against E. faecalis, facultative anaerobic bacteria and yeasts [15, 27]. Another disadvantage is that it is often not possible to remove $Ca(OH)_2$ completely from the root canal system. Hence, the use of $Ca(OH)_2$ as root canal medication has been discussed controversially recently [15, 27].

Because the removal of $Ca(OH)_2$ is frequently incomplete [21], 20–45 % of the root canal wall dentine is covered with residue of the dressing, even after copious irrigation [20]. The disadvantage of remaining

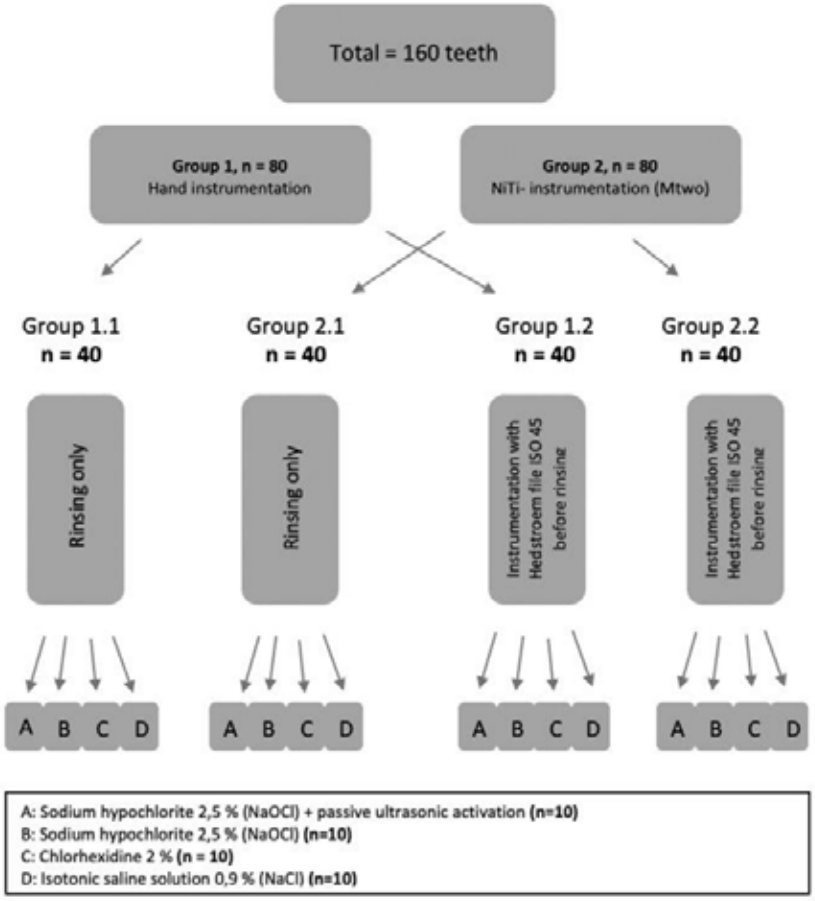


Fig. 1: Vesna Husemann

Figure 1 Experimental setup.

$Ca(OH)_2$ is the possible negative impact on root canal filling materials and their properties. Residual $Ca(OH)_2$ may reduce sealer adaptation on the root canal wall dentine [5, 34] and may hinder the penetration of sealer into dentinal tubules [7], thus reducing bond-strength of epoxy resin-based sealers [12], resin-based sealers [5], silicon-based sealers [10], and zinc-oxide eugenol-based sealers [17]. Furthermore, residual $Ca(OH)_2$ can reduce the processing time, shorten the setting time and increase the film thickness of the sealer [22]. In conclusion, $Ca(OH)_2$ may interfere with the root canal sealer, compromise the quality of the root canal filling and hence of the whole treatment [15, 27]. Finally, remaining $Ca(OH)_2$ may be washed out by body fluids or will be resorbed from the apical part of the root canal over time resulting in apical leakage and treatment failure [28]. Therefore, root canal sealers may show leakage after $Ca(OH)_2$ applications [5]. In addition, $Ca(OH)_2$ used as long-term root canal dressing may increase the risk of root fracture [1]. Thus, $Ca(OH)_2$ needs to be removed completely from the root canal system [15, 27].

With regard to the root canal taper after preparation, it was found that irrigation of root canals with a greater taper allows improved disinfection of the entire root canal system [6, 26]. However, it is still unclear whether a lager diameter of the root canal and a greater conicity, and thus a higher volume of irrigation solution also lead to improved removability of $Ca(OH)_2$. Therefore, the aim of the present study was to investigate different methods and irrigation solutions for the removal of aqueous calcium hydroxide suspension ($Ca(OH)_2$) from root canals of extracted human teeth. The following null hypotheses should be tested:

1. Preparing the root canals before medication with NiTi-files with an enlarged taper (4 % instead of 2 %)

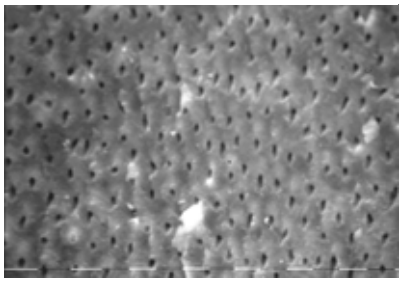


Figure 2a Grade 1 = no calcium hydroxide remnants visible, all dentinal tubules are patent.

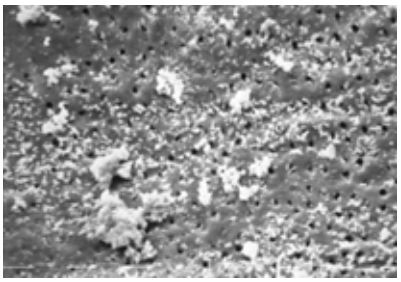


Figure 2b Grade 2 = small amounts of calcium hydroxide remnants visible, some dentinal tubules are open.

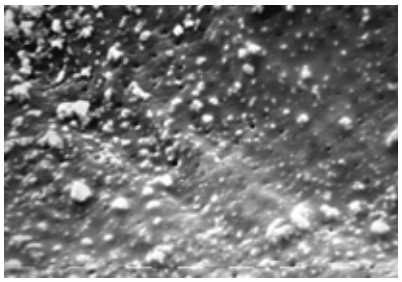


Figure 2c Grade 3 = Calcium hydroxide homogeneously coats almost the entire root canal wall, only isolated dentinal tubules are open.

Figure 2a–e Examples of the electron microscopic evaluation of scores 1 to 5, magnification 2,500×.

has no positive influence on the removability of $Ca(OH)_2$ by root canal rinsing solutions.

2. Further preparation of the root canals from ISO 40 to ISO 45 with hand instruments before root canal irrigation has no positive influence on the removability of $Ca(OH)_2$.

Materials and methods

All full-aged participants provided their written informed consent that the extracted teeth may be used for study purposes. The handling of all human samples followed strictly the "Declaration of Helsinki".

Prior to root canal treatment, all teeth were investigated under a stereomicroscope (Expert DN, Müller Optronic, Erfurt, Germany) to exclude cracks or root resorption. Buccal and proximal radiographs were taken to ensure a single root canal with an intact apical region and a single apical foramen. 160 extracted human single-rooted upper incisor teeth that showed a round root canal with a width of approximately ISO size 15 near the apex were included in this study. The root canal width was examined with silver points ISO size 15 and 20 (VDW, Munich, Germany). Patency of the canal was determined with K-files ISO size 10 (VDW). The working length was defined by measuring the length of the initial instrument (K-Files ISO size 10; VDW) visible at the major apical foramen minus 1 mm.

The total of 160 teeth was divided into two groups: group 1 included 80 teeth in which the root canals were prepared by hand instrumentation using Reamers and Hedstrom files from ISO size 15 up to ISO size 40 (VDW). Group 2 included also 80 teeth in which the root canals were instrumented by rotary NiTi-files up to size 04/40 (Mtwo; VDW) using the torque-limited endodontic motor VDW.Silver (VDW) with the settings according to the manufacturer's instructions. The instruments were cleaned after 3 pecks (in-and-out move) and the root canal was irrigated with 5 ml NaOCl 2.5 % during the instrumentation. After instrumentation the root canal system was irrigated with 5 ml isotonic saline solution (NaCl) 0.9 % and 2 ml EDTA 17 % to remove the smear layer. Afterwards, again 5 ml NaCl 0.9 % were applied as final irrigant. A 30 g open needle (Miraject; Hager & Werken, Duisburg, Germany) was used to perform the irrigation during and after instrumentation, in which the needle was inserted as deep as possible into the canal but without binding. The root canals were dried by paper points afterwards.

After drying, all root canals were filled with an aqueous $Ca(OH)_2$ suspension (Calxyl blau, OCO, Dirmstein, Germany) by using a Lentulo (VDW) which reached the exact working length of each tooth. Thereafter, the access cavity was temporised by using Cavit (3M ESPE, Seefeld, Germany) and all samples were stored in an incubator (Wärme- und Trockenschrank, Heraeus, Hanau, Germany) in NaCl 0.9 % at 37 °C and 100 % humidity for 7 days.

Before removing $Ca(OH)_2$ from the root canals, each group (group 1 and 2) was again divided, so that 4 groups with 40 teeth resulted (groups 1.1, 1.2, 2.1, 2.2). The samples of Group 1.1 and 2.1 were rinsed only with an irrigation solution to remove $Ca(OH)_2$ from the root canals. In group 1.2 and 2.2 the root canals were instrumented with Hedstrom files ISO size 45 (VDW) right before irrigation to remove $Ca(OH)_2$ also mechanically. Four different irrigation solutions or methods were used so that 10 teeth in each group were rinsed with the same solution or method. The following irrigation solutions were used:

A: Sodium hypochlorite 2.5 % (NaOCl) (Hospital pharmacy of the University Hospital, Münster, Germany) + passive ultrasonic activation (VDW Ultra; VDW)
B: Sodium hypochlorite 2.5 % (NaOCl)
C: Chlorhexidine 2 % (Chlorhexidindigluconat-Lösung 2 %; Engelhard Arzneimittel, Niederdorfelden, Germany)
D: Isotonic saline solution 0.9 % (NaCl) (Hospital pharmacy of the University Hospital, Münster, Germany)

5 ml of the respective irrigation solution were applied in each root canal using a 30 g open needle whereby the needle was inserted as deep as possible into the canal but without binding. In all groups where NaOCl was activated this was done using a file

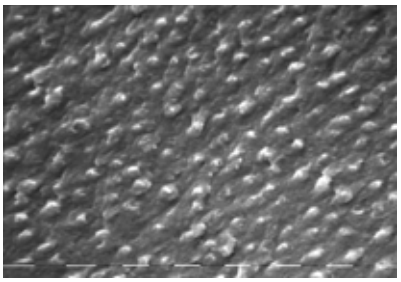


Figure 2d Grade 4 = the entire root canal wall is homogeneously covered with calcium hydroxide, no patent dentinal tubules.

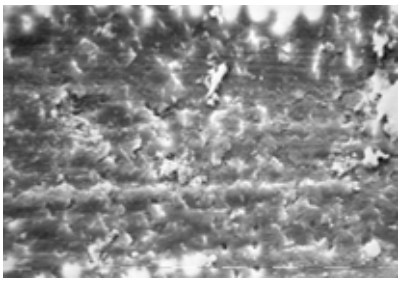


Figure 2e Grade 5 = the complete root canal wall is covered with a distinct layer of calcium hydroxide.

Photos: Vesna Husemann

size 25 (Irri-S 21/25; VDW) with a frequency of 28,000 Hz as recommended by the manufacturer. The Irri-S tip was placed 2 mm short of working length and in-and-out movements with an amplitude of 5 mm were performed. Irrigation for passive ultrasonic activation (PUA) was repeated 2 times for 30 s. Care was taken to ensure that the volume (5 ml) and the contact time of the irrigation solution (2 min) in the root canal were identical in all groups.

Thereafter, the samples were prepared for scanning electron microscopic (SEM) observation to assess the $Ca(OH)_2$ remnants on the root canal walls. All teeth were carefully split longitudinally to allow visualization of the root canal lumen. Afterwards, the root halves were attached to a sample plate (Provag, Oestrich-Winkel, Germany) by using an electrically conductive glue (Leit-C nach Göcke; Chemikalien Neubauer, Münster, Germany). To ensure drying of the glue, the samples were stored dustproof for 24 hours. Afterwards the specimens were coated in a thin film of gold (95 nm) using a sputtering technique to provide conductivity of each sample (Sputter Coater, Balzers Union, Balzers, Liechtenstein). The specimens were divided into 3 sections by marking them with a waterproof pen so that a coronal, middle and apical third of the root canal resulted.

Finally, the specimens were observed under the scanning electron microscope (Philips PSEM 500X, Eindhoven, Netherlands). The visual evaluation of the root canal halves was carried out at 2,500× magnification, so that the root canal areas could be visibly recorded, examined, evaluated and photographically documented.

In order to assess the $Ca(OH)_2$ remnants on the root canal walls as well as to evaluate the effectiveness of each irrigating solution and its application method, the scoring system by Hülsmann et al. [14] was modified as follows:

- **Grade 1** = no $Ca(OH)_2$ remnants visible, all dentinal tubules are patent.
- **Grade 2** = small amounts of $Ca(OH)_2$ remnants visible, some dentinal tubules are open.
- **Grade 3** = $Ca(OH)_2$ homogeneously coats almost the entire root canal wall, only isolated dentinal tubules are open.
- **Grade 4** = the entire root canal wall is homogeneously covered with $Ca(OH)_2$, no patent dentinal tubules.
- **Grade 5** = the complete root canal wall is covered with a distinct layer of $Ca(OH)_2$.

Statistical analyses

The grades were recorded for every single tooth at the coronal, middle and apical third of each root canal. In order to evaluate significant differences in $Ca(OH)_2$ removal within the different groups, the data were statistically evaluated using the Kruskal-Wallis-Test ($p < 0.05$) (MedCalc, Ostend, Belgium). The data were checked for normality before using the non-parametric test for statistical comparison.

Results

Only irrigating with NaOCl 2.5 % in combination with PUA showed significantly less $Ca(OH)_2$ remnants on the root canal walls compared to all other irrigation solutions and methods ($p < 0.05$) (Table 1). Instrument taper and an additional instrumentation right before root canal irrigation had no statistically significant influence on the removability of $Ca(OH)_2$ from the root canal ($p > 0.05$) (Table 2). Thus, neither the preparation with NiTi files taper 4 % instead of hand instruments taper 2 % nor an additional instrumentation with a Hedstrom file ISO size 45 before rinsing could decrease the amount of $Ca(OH)_2$ remnants on the root canal wall significantly.

In all groups where NaOCl in combination with PUA was used for root canal irrigation the highest amount of patent dentinal tubules was observed. Hence, this irrigating protocol mostly reached grade 1 or 2 from the scoring system except for 5 teeth which were classified as grade 3 in some root canal sections. None of the other rinsing solutions or methods yielded a single tooth section rated grade 1. No statistically significant differences were observed in all other specimens without the use of NaOCl plus PUA ($p > 0.05$). Furthermore, no statistically significant difference between the results of the 3 root canal sections (apical, middle or coronal third) was observed, independent of irrigation method and solution ($p > 0.05$). The amount of $Ca(OH)_2$ residues was equal in all areas of the root canal.

Discussion

In this in vitro study passive ultrasonic activation of NaOCl 2.5 % was significantly more effective in removing $Ca(OH)_2$ from the root canal walls than NaOCl without PUA or all other irrigation protocols tested ($p < 0.05$). In some root canals, passive ultrasonically activated NaOCl 2.5 % was able to remove the $Ca(OH)_2$ dressing completely, while

	NaOCl + PUA	NaOCl	CHX	NaCl
Score 1 in %	65.0	0.0	0.0	0.0
Score 2 in %	30.8	23.3	20.0	20.8
Score 3 in %	4.2	41.7	47.5	41.7
Score 4 in %	0.0	30.8	28.3	31.7
Score 5 in %	0.0	4.2	4.2	5.8

Table 1 Percentage of each irrigation solution and method regarding the different scores.

	Hand instrumentation	Rotating NiTi-files	CHX	NaCl
	Only rinsing	Instrumentation with Hedstrom file ISO size 45 right before rinsing	Only rinsing	Instrumentation with Hedstrom file ISO size 45 right before rinsing
	Group 1.1	**Group 1.2**	**Group 2.1**	**Group 2.2**
NaOCl + PUA	1/2/3	1/2/3	1/2/3	1/2/3
NaOCl	4	4	4	4
CHX	4	4	4	4
NaCl	4	4	4	4

Table 2 Statistical evaluation of the results. Statistically significant differences to other groups show 1/2/3, outcomes without significant differences show 4; Kruskal-Wallis-Test ($p < 0.05$).

no other irrigation solution or method could generate root canals with completely patent dentinal tubules. This result was independent from which cone (2% or 4%) was used to prepare the root canals and whether or not the root canals were instrumented with a Hedstrom file ISO size 45 to mechanically remove $Ca(OH)_2$ before irrigation. Hence, the null hypotheses were therefore accepted: neither a larger taper nor instrumentation prior to root canal irrigation has a significant influence on the removability of $Ca(OH)_2$ from the root canal. To the best of our knowledge, this is the first study to evaluate the influence of the instrument taper on the removability of $Ca(OH)_2$.

Rinsing solely with NaOCl 2.5% without PUA is significantly less effective than with PUA. This finding is in accordance with previous investigations [24, 31, 32]. Despite the superior cleaning effect of ultrasonically activated NaOCl, it had to be noted that all experimental groups showed remnants of $Ca(OH)_2$ which was also observed in other studies [8, 19–22, 24, 29, 31, 32, 34].

The overall evaluation showed no statistically significant difference in the effectiveness of the removal regarding the 3 sections (apical, middle and coronal third) of the root canal ($p < 0.05$), which is in line with previous findings [8, 9]. On the contrary, there are reports that the removal of $Ca(OH)_2$ in the apical third was more effective than the removal in the coronal part [24, 29]. In contrast, Silva et al. [31] observed a higher percentage of remaining $Ca(OH)_2$ in the apical region than in the coronal region. This may be explained by the fact that $Ca(OH)_2$ may tend to accumulate apically during the removal procedure [19]. A conical morphology of the root canal with a smaller diameter in the apical region may lead to reduced irrigation efficiency in this area [4, 16].

The instrumentation using a Hedstrom file ISO size 45 before rinsing had no statistically significant effect on removing $Ca(OH)_2$ from the root canal ($p > 0.05$), which is in accordance with another study [31]. In contrast, Salgado et al. [30] reported an improved removal of $Ca(OH)_2$ compared to irrigation alone when a re-instrumentation was performed with a master apical file.

It is well accepted that NaOCl irrigation leaves significantly more $Ca(OH)_2$ on the root canal walls than rinsing with EDTA or citric acid [18, 33]. This might be explained by the fact that NaOCl has a limited ability to dissolve inorganic substances [3, 34], such as calcium, whereas citric acid and EDTA are decalcifying solutions and undergo neutralization reactions with $Ca(OH)_2$. Ballal et al. [3] stated that ultrasonically activated 17% EDTA and 10% citric acid solution were able to remove $Ca(OH)_2$ completely from root canals. However, other studies do not agree with these findings [32]. In the present study these rinsing solutions were not used, as the main question of this study was not to evaluate the solutions itself but to assess the effects of instrument taper and instrumentation before root canal irrigation on the removal of $Ca(OH)_2$.

The design of the present study which assessed the cleanliness of the complete root canal wall was the same as used in previous investigations [20, 23]. Some other studies used a groove model [11, 19, 24] to standardize the procedure as the location and size of the groove does not vary as much as the natural root canal anatomy. This might be an advantage but disadvantage at the same time, as the groove model seems to be easier and probably more reproducible in evaluating the outcomes when compared to assessing the total surface of the root canal wall. Nevertheless, the complexity of the natural

root canal anatomy and its clinical relevance cannot be replicated in the groove model. One could assume that it may be easier to remove $Ca(OH)_2$ from artificial grooves than from natural isthmuses or irregular surfaces of natural root canal walls, which could possibly lead to an overestimation of the removal efficacy of irrigation solutions.

Conclusion

From the results of this study, it can be concluded that the removal of $Ca(OH)_2$ is significantly more effective when PUA is used as it leads to less $Ca(OH)_2$ remnants on the root canal walls ($p < 0.05$). All irrigation protocols without PUA (NaOCl 2.5 %, CHX 2 %, NaCl 0.9 %) did not show statistically significant differences among each other ($p > 0.05$). The taper of the root canal preparation before medication with $Ca(OH)_2$ did not influence the results significantly ($p > 0.05$). The re-instrumentation using a Hedstrom file ISO size 45 before irrigation did not affect the removability of $Ca(OH)_2$ from the root canal significantly ($p > 0.05$) either. Furthermore, statistically significant differences in the cleanliness of the apical, middle and coronal region of the root canal were not observed ($p > 0.05$).

Conflicts of interest

The authors deny any conflict of interest related to this study. This research received no external funding.

References

1. Andreasen JO, Farik B, Munksgaard EC: Long-term calcium hydroxide as a root canal dressing may increase risk of root fracture. Dent Traumatol 2002; 18: 134–137

2. Athanassiadis B, Abbott PV, Walsh LJ: The use of calcium hydroxide, antibiotics and biocides as antimicrobial medicaments in endodontics. Aust Dent J 2007; 52(1 Suppl): S64–82

3. Ballal NV, Kumar SR, Laxmikanth HK, Saraswathi MV: Comparative evaluation of different chelators in removal of calcium hydroxide preparations from root canals. Aust Dent J 2012; 57: 344–348

4. Balvedi RPA, Versiani MA, Manna FF, Biffi JCG: A comparison of two techniques for the removal of calcium hydroxide from root canals. Int Endod J 2010; 43: 763–768

5. Böttcher DE, Hirai VHG, Neto UXDS, Grecca FS: Effect of calcium hydroxide dressing on the long-term sealing ability of two different endodontic sealers: an in vitro study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2010; 110: 386–389

6. Brunson M, Heilborn C, Johanson DJ, Cohenca N: Effect of apical preparation size and preparation taper on irrigant volume delivered by using negative pressure irrigation system. J Endod 2010; 36: 721–724

7. Calt S, Serper A: Dentinal tubule penetration of root canal sealers after root canal dressing with calcium hydroxide. J Endod 1999; 25: 431–433

8. Camargo CHR, Leal FM, Silva GO et al.: Efficacy of different techniques for removal of calcium hydroxide-chlorhexidine paste from root canals. Gen Dent 2016; 64: e9–12

9. Chockattu S, Deepak B, Goud K: Comparison of efficiency of ethylenediaminetetraacetic acid, citric acid, and etidronate in the removal of calcium hydroxide intracanal medicament using scanning electron microscopic analysis: An in-vitro study. J Conserv Dent 2017; 20: 6–11

10. Contardo L, De Luca M, Bevilacqua L et al.: Influence of calcium hydroxide debris on the quality of endodontic apical seal. Minerva Stomatol 2007; 56: 509–517

11. Donnermeyer D, Wyrsch H, Bürklein S, Schäfer E: Removal of calcium hydroxide from artificial grooves in straight root canals: sonic activation using EDDY versus passive ultrasonic irrigation and XPendo Finisher. J Endod 2019; 45: 322–326

12. Guiotti FA, Kuga MC, Duarte MAH et al.: Effect of calcium hydroxide dressing on push-out bond strength of endodontic sealers to root canal dentin. Braz Oral Res 2014; 28: 1–6

13. Hermann B: Kalziumhydroxid als Mittel zum Behandeln und Füllen von Zahnwurzelkanälen (Dissertation). Julius-Maximilians-Universität, Würzburg 1920

14. Hülsmann M, Rümmelin C, Schäfers F: Root canal cleanliness after preparation with different endodontic handpieces and hand instruments: a comparative SEM investigation. J Endod 1997; 23: 301–306

15. Hülsmann M, Schäfer E: Probleme der Desinfektion. In: Hülsmann M, Schäfer E (eds): Probleme in der Endodontie. Prävention, Identifikation und Management. 2nd ed., Quintessence Publishing, Berlin 2019, 255–289.

16. Kenee DM, Allemang JD, Johnson JD et al.: A quantitative assessment of efficacy of various calcium hydroxide removal techniques. J Endod 2006; 32: 563–565

17. Kim SK, Kim YO: Influence of calcium hydroxide intracanal medication on apical seal. Int Endod J 2002; 35: 623–628

18. Kuştarcı A, Er K, Siso SH et al.: Efficacy of laser-activated irrigants in calcium hydroxide removal from the artificial grooves in root canals: an ex vivo study. Photomed Laser Surg 2016; 34: 205–210

19. Lambrianidis T, Kosti E, Boutsioukis C, Mazinis M: Removal efficacy of various calcium hydroxide/chlorhexidine medicaments from the root canal. Int Endod J 2006; 39: 55–61

20. Lambrianidis T, Margelos J, Beltes P: Removal efficiency of calcium hydroxide dressing from the root canal. J Endod 1999; 25: 85–88

21. Ma JZ, Shen Y, Al-Ashaw AJ et al.: Micro-computed tomography evaluation of the removal of calcium hydroxide medicament from C-shaped root canals of mandibular second molars. Int Endod J 2015; 48: 333–341

22. Margelos J, Eliades G, Verdelis C, Palaghias G: Interaction of calcium hydroxide with zinc oxide-eugenol type sealers: a potential clinical problem. J Endod 1997; 23: 43–48

23. McGill S, Gulabivala K, Mordan N, Ng Y-L: The efficacy of dynamic irrigation using a commercially available system (RinsEndo) determined by removal of a collagen 'bio-molecular film' from an ex vivo model. Int Endod J 2008; 41: 602–608

24. Pabel A-K, Hülsmann M: Comparison of different techniques for removal of calcium hydroxide from straight root canals: an in vitro study. Odontology 2017; 105: 453–459

25. Peters OA, Laib A, Göhring TN, Barbakow F: Changes in root canal geometry after preparation assessed by high-resolution computed tomography. J Endod 2001; 27: 1–6

26. Peters OA, Paqué F: Shaping the root canal system to promote effective disinfection. In: Cohenca N (ed): Disinfection of Root Canal Systems: The Treatment of Apical Periodontitis. Wiley Blackwell Publishing, Ames 2014, 91–108

27. Peters OA, Peters CI, Basrani B: Cleaning and shaping the root canal system. In: Berman LH, Hargreaves KH (eds). Cohen's Pathway of the Pulp. 12th ed., Elsevier Publishing, St. Louis 2021, 236–303

28. Ricucci D, Langeland K: Incomplete calcium hydroxide removal from the root canal: a case report. Int Endod J 1997; 30: 418–421

29. Rödig T, Vogel S, Zapf A, Hülsmann M: Efficacy of different irrigants in the removal of calcium hydroxide from root canals. Int Endod J 2010; 43: 519–527

30. Salgado RJC, Moura-Netto C, Yamazaki AK et al.: Comparison of different irrigants on calcium hydroxide medication removal: microscopic cleanliness evaluation. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009; 107: 580–584

31. Silva LJM, Pessoa OF, Teixeira MBG et al.: Micro-CT evaluation of calcium hydroxide removal through passive ultrasonic irrigation associated with or without an additional instrument. Int Endod J 2015; 48: 768–773

32. Taşdemir T, Celik D, Er K et al.: Efficacy of several techniques for the removal of calcium hydroxide medicament from root canals. Int Endod J 2011; 44: 505–509

33. Wang Y, Guo L-Y, Fang H-Z et al.: An in vitro study on the efficacy of removing calcium hydroxide from curved root canal systems in root canal therapy. Int J Oral Sci 2017; 9: 110–116

34. Wiseman A, Cox TC, Paranjpe A et al.: Efficacy of sonic and ultrasonic activation for removal of calcium hydroxide from mesial canals of mandibular molars: a microtomographic study. J Endod 2011; 37: 235–238

Photo: T. Dammaschke

Corresponding author:
PROF. DR. TILL DAMMASCHKE
Department of Periodontology and Operative Dentistry
Westphalian Wilhelms-University
Waldeyerstr. 30
48149 Münster, Germany
E-mail: tillda@uni-muenster.de

Christian Graetz, Bilal Al-Nawas, Paulina Düffert, Lutz Jatzwauk, Miriam Cyris, Markus Tröltzsch, Kai Voss, Stefan Rupf, Lena Katharina Müller

Spray mist and aerosol control in dental room air – summary of current evidence

Introduction: An evidence-based, balanced discussion of the facts regarding the reduction of infection risk during the SARS-CoV-2 pandemic by aerosol-controlling measures in dental practice has not yet been fully conducted. Therefore, the current state of knowledge on spray mist and aerosol control in dental offices will be reported in order to present conclusions on risk reduction of aerogen-transmitted infectious diseases in the dental practices.

Methods: Results of studies directly related to spray mist and aerosol control in a dental office, as well as recommendations from publications including national position statements and guidelines for dentistry, are discussed in a narrative format.

Results: Decision-making at the onset of the SARS-CoV-2 pandemic was hampered by the limited evidence base, but could be improved as the pandemic duration progressed by publishing more studies about spray mist and indoor aerosol control. Study results on the routine use of dental suction systems (intraoral) can be used to specify limits to their effectiveness in aerosol reduction. Similarly, findings on ubiquitously available natural room ventilation shows very high air exchange per hour (ACH) of up to 40 with continuous cross-ventilation under optimal room geometry with opposing windows, whereas only a limited additional effect can be expected for decentralized mobile air cleaning (DMAC) devices in reducing smaller aerosol particles in the treatment room.

Discussion: For optimized infection protection in dentistry, in addition to natural room ventilation and compliance with all known hygiene guidelines, the use of intraoral suction (high-volume evacuator (HVE) with a suction volume > 250 l/min) using a sufficiently large suction cannula (opening ≥ 10 mm), positioned close to the aerosol-generating treatment field, is mandatory. From a clinical point of view, supplementary DMAC devices provide a negligible additional reduction effect during aerosol-generating activities. Room air exchange by natural room ventilation in combination with HVE systems shows a high efficiency and continues to be the standard procedure in dental practices. Future studies must clarify whether DMAC devices with

Clinic for Dental Conservation and Periodontology at the University Hospital Schleswig-Holstein, Campus Kiel: Prof. Dr. Christian Graetz (corresponding author), Paulina Düffert, Dr. Miriam Cyris
Clinic and Polyclinic for Oral and Maxillofacial Surgery, Plastic Surgery, University Medicine of the Johannes Gutenberg University Mainz: Prof. Dr. Dr. Bilal Al-Nawas, Dr. Lena Katharina Müller
University Hospital Carl Gustav Carus at the TU Dresden, Division Hospital Hygiene/ Environmental Protection, Fetscherstr. 74, 01307 Dresden: Prof. Dr. Lutz Jatzwauk
Center for Dental, Oral and Maxillofacial Medicine Ansbach, Dr. Dr. Tröltzsch, Maximilianstr. 5, 91522 Ansbach: Dr. Dr. Markus Tröltzsch
Dental practice Dr. Voss, Am Alten Bahnhof 1, 24245 Kirchbarkau: Dr. Kai Voss
Professorship for Synoptic Dentistry, Clinic for Dental Preservation, Periodontology and Preventive Dentistry, Saarland University Hospital, Homburg/Saar: Prof. Dr. Stefan Rupf
Translation from German: Yasmin Schmidt-Park
Citation: Graetz C, Al-Nawas B, Düffert P, Jatzwauk L, Cyris M, Tröltzsch M, Voss K, Rupf S, Müller LK: Spray mist and aerosol control in dental room air – summary of current evidence. Dtsch Zahnärztl Z Int 2021; 3: 283–289
Peer-reviewed article: submitted: 09.07.2021, revised version accepted: 23.08.2021
DOI.org/10.3238/dzz-int.2021.0035

ACH ≥ 6 can be a supplement in exceptional situations with a high risk of infection, for example, when no intraoral suction is used or protective/hygiene measures can only be observed to a limited extent.

Conclusion: Established hygiene concepts and protective measures, including room ventilation with fresh air, have proven to be sufficiently effective in dental practice even during the SARS-CoV-2 pandemic.

Keywords: aerosol; guidelines; aerogene-transmitted infectious diseases; SARS-CoV-2

Introduction

Scientific statements and guidelines provide the basis for decision-making for dental activity on the basis of current knowledge. However, this presupposes that 1. corresponding knowledge is available in the form of studies of high evidence with direct relevance and 2. corresponding publications with recommendations are also known to practicing dentists. In the course of the SARS-CoV-2 pandemic, it was observed that both aspects changed continuously. It must be critically noted that, especially in the initial phase of the pandemic, recommendations were published on the basis of assumptions due to a lack of evaluation bases. The SARS-CoV-2 pandemic affected almost all private and professional spheres of life. This often led to emotionally driven discourses on partially appropriate catalogs of measures but not to a desirable balanced discussion on facts about the risk of infection in dentistry. It is obvious that a retrospective view is always easier. Moreover, for the SARS-CoV-2 pandemic, decision-making was complicated, particularly in its early stages, because a very limited evidence base existed. Even at the present time, fundamentally important questions about the origin of the virus as well as its infectivity, e.g., after illness or vaccination, have not been conclusively resolved. Therefore, in this article, the authors would like to present conclusions for the future use of spray mist and aerosol control to minimize the risk of aerogenously transmitted infectious diseases in dental practices based on the latest evidence.

The following remarks must be preceded by the fact that there can only be an effective pandemic containment and a protection against infections if all known preventive measures are implemented. Examples are compliance with room ventilation, distance and hygiene rules and the wearing of medical or FFP-2 masks. For dental practices, however, it must be taken into account that patients cannot wear mouth/nose coverings during treatments and the close treatment contact with a distance of only around 30 cm between patients and the treatment team. There is no question that rubber dam application is very effective in reducing droplets and aerosols which are potentially contaminated by microorganisms [1, 3, 8, 25, 30, 35]. However, this protective measure is not always possible with the wide range of activities in the dental practice. Spray mist and aerosol-generating measures occur in close proximity to the dental staff. In addition, the patients release aerosols and droplets through speaking, breathing, and coughing. The spray mist is a mixture of droplets and droplet nuclei of different sizes, consisting of cooling water, (powder) particles, splashes of saliva, blood and microorganisms, and is generated during the use of high-speed instruments including sonic/ultrasonic scalers and powder water jets. If this spray mist is not properly extracted, a potentially infectious aerosol cloud is created. Since the beginning of the SARS-Cov-2 pandemic, 497 cases with infections with the SARS-Cov-2 virus in the dental sector have been reported to the Employer's Liability Insurance Association for Health Services and Welfare Care (Berufsgenossenschaft für Gesundheitsdienst und Wohlfahrtspflege, BGW) in Germany until June 2021, of which the BGW lists 143 as occupational cases (query as of 01.06.2021). Even if underreporting must be assumed with regard to the published case numbers, this results in a prevalence of ≤ 0.1 % for SARS-CoV-2 infections among dental personnel [10], which can be seen as an indication of the high level of protection provided by established behavioral and hygienic measures in dentistry in Germany. Therefore, it has been proven to be useful to integrate the additional protective measures in the sense of a bundle of measures into recommendations already in force [28]. This can be seen in analogy to the precautionary approach of radiation protection [19], which means that the probability of exposure to SARS-CoV-2, the number of persons exposed, and the individual pathogen dose affecting a person are kept as low as reasonably achievable in dental practice. This set of measures has been shown to include room ventilation [19].

Room ventilation and pathogen transmission

Unlike outdoors, the transmission route plays a central role in an aerogenously transmissible infectious disease indoors. But especially in the case of SARS-CoV-2 there is still controversy about the proportion of direct contact or other routes including droplets [13] and airborne transmission [39], that are responsible for virus spread [23] (Figure 1).

Physically, droplets with 4–8 µm size will fall to the ground within 20–90 minutes according to indoor air conditions, while aerosol particles with sizes smaller than 4 µm can remain in the air for up to 30 hours [9]. However, as droplets lose water and become smaller with lower humidity (at a droplet size < 10 µm, the water fraction evaporates within splits of a second), and droplet nuclei are formed. Indoors they can remain suspended for hours and are transported with the airflow [19, 37]. This might inactivate bacteria and viruses, thus reducing the infectivity of the indoor air. It is undisputed that droplets contain significantly more pathogens than smaller droplet nuclei due to their size, and thus their infectious dose is higher. Especially in closed rooms, despite the smaller amount of pathogens in the aerosol, there is a higher risk of disease transmission because the particles do not dry out,

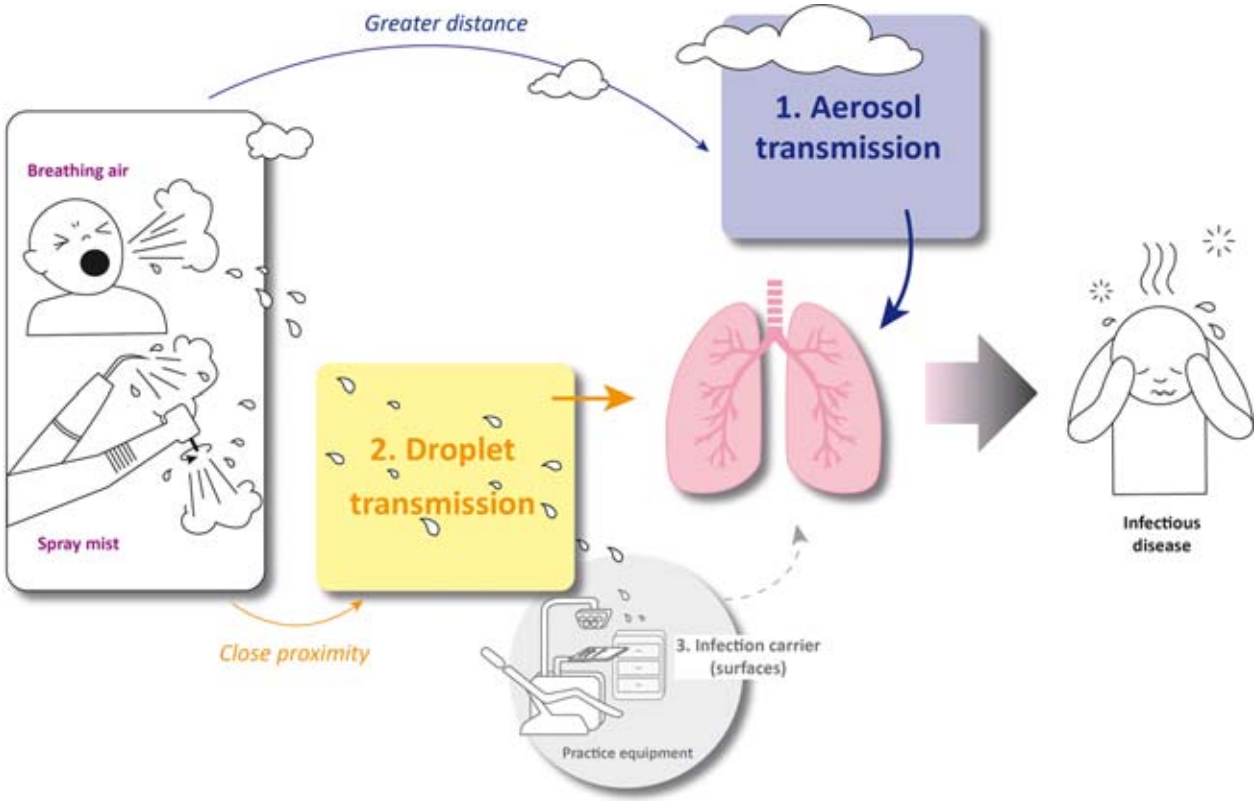


Figure 1 Schematic representation of possible transmission routes using the example of the SARS-CoV-2 virus in dental practices (Note: Transmission via surfaces cannot be ruled out, although the authors consider this route to be rather less significant based on corresponding studies from medical facilities [4]).

especially in high humidity, and are kept in suspension for a long time. Therefore, the circulation and exchange of particles in the room air (air exchange) plays a central role in infection control. It can be implemented naturally (e.g., ventilation with fresh air through open windows) or supported by technical systems (e.g., room ventilation system, decentralized mobile air purification units) (Figure 2). The air exchange rate (ACH) describes the amount of air supplied per room volume per hour.

Natural ventilation

In case of free ventilation, a distinction can be made between shock ventilation, cross ventilation and gap ventilation (Figure 2). Shock and cross ventilation can quickly lead to a dilution of aerosol-containing indoor air if a high temperature difference between in- and outdoor air is provided [18, 19]. However, the result of natural ventilation depends on quite a few factors that cannot be influenced, such as the outside temperature, wind direction and strength, as well as window size and position in the room. Also, after closing the window, the aerosol concentration in the treatment room will increase again. Gap ventilation by means of permanently tilted windows is insufficient (ACH: 0.3–1.5) and can be considered as a supplementary measure to shock or cross ventilation at most, with windows fully open for a short time (ACH: 0.3–4) [18, 19]. Even though cross-ventilation by opening 2 opposite windows in the building may be partly limited or even impossible during treatment due to the room architecture and privacy in dental offices, this is the most effective method (ACH: up to 40). To protect the patient's privacy but still minimizing aerosols efficiently it is therefore suggested to open opposite windows after dental treatments and while preparing for the following patient [19]. A smaller temperature difference especially during warmer summer months can lead to insufficient air exchange and a longer ventilation time (10 min) must be aimed for. During the colder winter months, sufficient air exchange is provided by high temperature differences already at a ventilation time of 3 min, which is also helpful in reducing energy loss during natural ventilation. In autumn, winter and spring, regular shock ventilation for 3–10 minutes following dental treatment is a practicable method of air exchange and thus also reduces aerosol concentrations in the treatment or waiting room [12]. However, longer ventilation durations of 10–15 minutes should be aimed for in the summer [22], as the air exchange rate may be lower than in other seasons due to the approximately equal temperatures outside and inside. Kienbaum et al. [19] therefore recommend that a ventilation plan is drawn up based on the type of ventilation (number of windows, doors if necessary), ventilation duration/interval (season) and additional ventilation occasions (specific treatment/exposure situations).

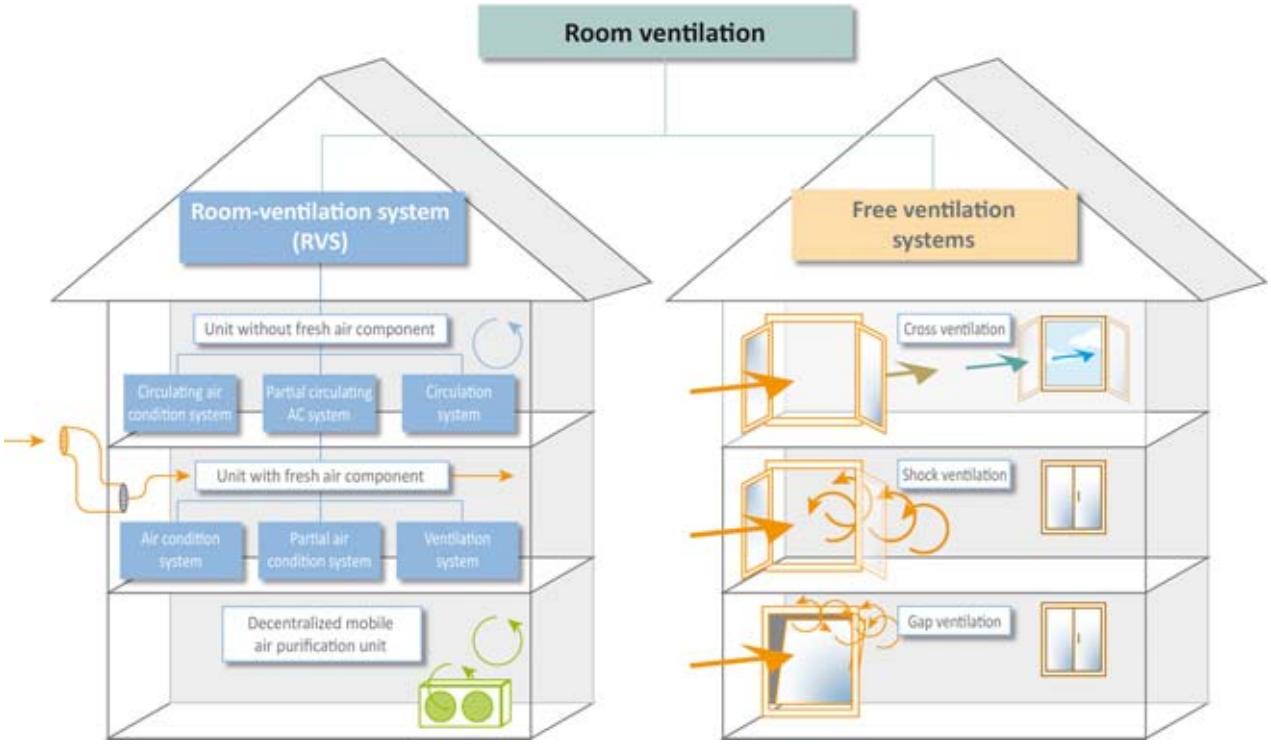


Fig. 1 + 2: C. Graetz

Figure 2 Simplified presentation on ventilation technology and its subsections according to DIN 1946 (part 1 of the standard), among others, as well as the possible room air ventilation.

Ventilation through technical equipment

The use of room ventilation systems (RVS) with defined ACH can be an alternative for larger practices/clinics with special structural requirements and/or for specific situations in summer and winter months, but also as a supplementary solution to natural ventilation. RVS systems in healthcare facilities (i.e. including dental practices) are regulated by DIN 1946/4. Their task is to heat or cool rooms, remove chemical pollutants or odors, minimize the colony count of microorganisms in the air (operating rooms), but above all to supply fresh air to rooms that are not naturally or sufficiently ventilated. Examination and treatment rooms are assigned to room class II. These rooms must be supplied with at least 40 m^3 of fresh air per hour and person present (if there is no window ventilation). This ensures an air exchange rate of about 6 times per hour. Taking into account this minimum proportion of fresh air and in order to minimize the heating costs for the fresh air supplied by the air handling system, the use of recirculated air is permissible. Fresh air and recirculated air are processed together (heated, cooled, filtered and, if necessary, humidified). The air is passed through 2 filter stages of classes F7 and F9. According to EN 779, the average efficiency of F9 filters is 95 % for particles of 0.4 µm diameter (i.e. including droplet nuclei).

According to DIN 1946/4, recirculating air cooling units (without fresh air component) are also possible in rooms in which a supply of fresh air is possible through sufficient window ventilation, if the air is returned to the same room from which it was taken (air-conditioning split units). At present, these must also be equipped with filters of classes F7 as well as F9. In general, devices in recirculation mode without filters (e.g. stand fans, mobile air conditioners, fan heaters) should be avoided in dental treatment rooms, as they do not lead to a reduction in aerosol concentrations, but can rather contribute to a distribution of aerosols in the room through the air flow. If operation is nevertheless necessary, care should be taken to ensure regular, intensive natural room ventilation [19].

Decentralized mobile air cleaning units

When neither sufficient natural ventilation nor technical room air systems with fresh air operation and filtration are operated, the additional use of decentralized mobile air cleaning devices (DMAC) is currently being discussed in the context of the pandemic [27, 29, 36]. There is a wide range of device types that are designed to separate the intake room air by various processes (UV, ionization, filtration, etc.) or to inactivate airborne substances, and then discharge them back into the same room. The air flow rate of the units and the achievable ACH, i.e. how quickly the relevant particles can be filtered out of the room air, play a decisive role here. Effective devices with high ACH requiere a high air volume flow. At this point, it has to be said that the high air volume flow leads to high sound pressure levels and thus consecutively to noise pollution [2]. Chavis et al. [2] measured up to 86 dB (comparative measurement tooth preparation without DMAC: 82 dB) when a DMAC was used at maximum suction power and

tooth preparation was performed simultaneously. On the other hand, Comisi et al. [5] measured sound pressure levels between 87 dB and 89 dB when operating a high-power intraoral suction system. When using a prototype 3D-printed lip retractor with internal suction and funnel, even up to 99 dB could be measured. In this experimental study, the sole operation of a DMAC was even associated with the lowest noise levels (less than 80 dB) [5]. These elevated sound pressure levels may not only affect intercommunication and patient comfort, but also make patient monitoring more difficult for staff.

For DMAC, as for the operation of an air handling unit, a possibly more cost-intensive unit operation and regular maintenance must be taken into account compared to natural room ventilation. Finally, the filtration performance of the units is also influenced by the room geometry and the arrangement in the room. In the case of particulate aerosols, there is no distribution equilibrium in the room [11], which is why an optimal placement of the devices should, for example, be near the treatment unit [2] – with all the disadvantages that this entails, such as annoyance due to noise, airflow, and a constricted room.

For a planned use of DMAC, only devices in which the room air is filtered by a separation process with classified H13 filters (or higher) should be considered. For all other devices with coarser filters, an insufficient effectiveness of the filtration of fine particles must be assumed [11]. Although the effectiveness of all devices can possibly still be increased by the aforementioned processes such as ozone or ions, scientific studies on effectiveness are lacking.

As our own experimental studies by the Kiel working group around Graetz et al. with a DMAC in the dental curriculum [15], and also observational studies in dental practices showed, the definition of the measurement method and experimental conditions is very complex [31, 41] and not directly comparable [16]; moreover, the results may often not be generalized [2]. Also, experimental studies with simulation of activities in dentistry may not be used to assess indoor air quality [40]. For example, the Kiel experiments were conducted using a phantom in a closed treatment room (16.94 m^2). The tested DMAC was aligned at a distance of 35 cm from a phantom head, on which various aerosol-generating treatments such as high-speed preparation or tooth cleaning using a powder water jet device were simulated. With the exception of the controls (no aerosol-generating treatment), a 16 mm suction cannula was always tested in combination with a saliva ejector using a dental high-volume evacuator (HVE) (suction volume (air) at the tip of the suction cannula: ≥ 300 l/min), in each case with versus without DMAC. With simultaneous monitoring of room air parameters such as CO_2 saturation, temperature, and air ventilation, the particle number concentration (PNC) of aerosols was recorded by an optical method using scattered light from a cleanroom counter (LasAir III, PMS Inc., USA). A mean ACH of 3 h^{-1} was determined for the DMAC, and only for particles with small diameters (0.1–0.3 µm) was there a significant reduction ($p < 0.001$) when the DMAC was used in addition to conventional intraoral suction [15]. In contrast to other experimental studies, which also demonstrated a further significant reduction for droplets and splashes by means of additional DMAC [2], the authors of the Kiel working group did not observe any additional reduction in room air concentration for particles with a larger diameter compared to the sole intraoral application of the HVE (0.5–5.0 µm; $p = 0.089$).

Intraoral dental suction systems

The intraoral use of a spray mist evacuation system is an established measure in the context of most dental treatments and thus already makes a decisive contribution to adequate hygiene and infection control [14, 32]. To ensure this function, HVEs with a suction volume (air) of ≥ 250 l/min have been described [34] and are regulated by ISO 10637:2018 (German version EN ISO 10637:2018). This describes not only the design of the central suction machine, but also notes on piping. Both the suction power and the diameter of all pipes, including the applied suction cannula, must be considered in the design and for the operation of an optimal dental suction system. For optimal risk reduction of aerogenically transmissible infectious diseases during spray mist generating interventions, suction cannulas with secondary air inlets (preventing stuck suction and thus blocking of the cannula) with diameters > 10 mm are recommended [28]. Suction with a narrow saliva ejector (diameter < 8 mm) and suction volume < 200 l/min is unsuitable for the reduction of aerosols [20], even though liquids can be eliminated sufficiently from the oral cavity. Rupf et al. [33] were able to show that fine particle aerosols released in the oral cavity of a phantom are only reduced by high-volume suction. Therefore, in addition to the technical requirements, the role of the optimal suction technique should be discussed within the practice team to ensure optimal infection control in the daily routine. Unfortunately, as already mentioned, suctioning with HVE systems leads to noise emissions that should not be underestimated, and these can make internal communication between practitioner and assistant as well as between patients more difficult. As already discussed for the previous technical systems, this also requires regular inspection (practice team) and maintenance (manufacturer-specific), for example, to counteract deposits with subsequent displacement/constriction of the inner tube diameters.

Summary discussion of the internal and external evidence

Even before the onset of the SARS-CoV-2 pandemic, it was known that dental activities are associated with the release of aerosols and particles that may have adverse health effects [26, 38]. According to current studies, effective reduction of aerosols with potential risk for aerogenically transmitted infectious disease is most easily achieved via natural ventilation. Technical filtration of room air by means of air handling systems is possible, but the use of DMAC de-

vices has only been described as a complementary measure for rooms in which primary infection control measures cannot be implemented adequately [11]. Operationally, every dental practice in Germany has a HVE unit that primarily succeeds in aspirating liquids from the patient's oral cavity and, at the same time, can effectively reduce the potentially contaminated spray rebound [14, 32] – corresponding to primary infection control. Compared with the routine operation of such configured HVE systems, DMAC devices can represent a complementary measure for the control of potentially infectious aerosols only in small to medium-sized practice rooms [6, 15, 18], always associated with not inconsiderable acquisition and operating costs of the devices (e.g., regular cleaning or replacement of the HEPA (high-efficiency particulate air) filters so that they do not themselves become a source of microorganisms and air pollutants [11, 18]), noise, or a limitation of space. Although HVE systems also require regular maintenance, their use is familiar in dental practice, and with an adequately sized and correctly positioned intraoral suction cannula and a suction volume flow (air) of approximately 300 l/min, aerosols from the patient's mouth can be significantly reduced during use [15]. In a study of SARS-CoV-2 and other microorganisms in dental aerosols with 28 participants, salivary bacteria were detected in the condensed aerosol in only 8 individuals [24]. Meethil et al. [24] found no viruses in the generated aerosol despite detectable SARS-CoV-2 viruses in the saliva of some asymptomatic patients. These results should be interpreted cautiously, and it must also be kept in mind that aerosol removal only ever occurs when suction cannulae are used at all due to measures involving spray mist generation. In addition, the results indicate that exposure to pathogens from saliva cannot be completely prevented in all cases despite the use of an HVE. In certain dental activities, for example intraoral examinations, aerosols will also occur, but diameter-optimized suction cannulas in particular are generally not used in this case.

Conclusion

For optimized infection protection in dentistry, high-volume intraoral suction during aerosol-generating treatments is mandatory in addition to compliance with all known hygiene guidelines [24, 28, 34]. For this purpose, HVE (according to ISO 10637:2018 type 1 with a suction volume > 250 l/min) in combination with a suction cannula that has a sufficiently large opening (≥ 10 mm) and is positioned close to the treatment field have proven effective [7, 14, 34]. It can significantly reduce aerosol and droplet dispersion in the treatment environment directly [7, 14, 17, 21, 32]. Although additionally used DMAC devices could cause a further significant reduction especially of smaller aerosol particles in the treatment room [15, 29, 36], but especially of the spray mist/droplet generating activities the effect is negligible from a clinical point of view, because the mandatory HVE devices already cause a significant reduction intraorally [15]. Thus, during dental treatment, both staff and patients appear to be largely protected from exposure to potential pathogens when the bundle of measures already postulated several times [28] is applied [24]. Even though natural ventilation is highly dependent in its efficiency on external and uninfluenceable variables (temperature difference indoor and outdoor air, wind conditions, room architecture), it is the simplest measure and almost always available measure with a high ACH and should be replaced only in exceptional cases. DMAC devices, even those with high ACH (≥ 6) and HEPA filters according to DIN EN 1822, can only be a supplementary protective measure for example during a high incidence phase and simultaneous limited implementation of the bundle of measures for infection control. However, it should be emphasized once again that, due to the proven high effectiveness of the HVE systems used in Germany and natural room ventilation, the additional benefit of DMAC devices for improved infection control must be the subject of future scientific investigations.

Conflict of interest

The authors declare that there is no conflict of interest as defined by the guidelines of the International Committee of Medical Journal Editors. The authors C. Graetz, M. Cyris, P. Düffert indicate that they have conducted scientific studies in cooperation with manufacturers for HVE (Dürr Dental SE, 74321 Bietigheim-Bissingen, Germany) and DMAC devices (ULT, Löbau, Germany) on the efficacy of aerosol and spray mist reduction in dentistry over the past 5 years.

Acknowledgements

The authors thank Dr. Susanne Schorr for preparing the figures.

References

1. Ather A, Patel B, Ruparel NB, Diogenes A, Hargreaves KM: Coronavirus Disease 19 (COVID-19): Implications for clinical dental care. J Endod 2020

2. Chavis SE, Hines SE, Dyalram D, Wilken NC, Dalby RN: Can extraoral suction units minimize droplet spatter during a simulated dental procedure? J Am Dent Assoc 2021; 152: 157–165

3. Cochran MA, Miller CH, Sheldrake MA: The efficacy of the rubber dam as a barrier to the spread of microorganisms during dental treatment. J Am Dent Assoc 1989; 119: 141–4

4. Colaneri M, Seminari E, Novati S et al.: Severe acute respiratory syndrome coronavirus 2 RNA contamination of inanimate surfaces and virus viability in a health care emergency unit. Clin Microbiol Infect 2020; 26: 1094 e1–1094 e5

5. Comisi JC, Ravenel TD, Kelly A, Teich ST, Renne W: Aerosol and spatter mitigation in dentistry: Analysis of the effectiveness of 13 setups. J Esthet Restor Dent 2021; 33: 466–479

6. Curtius J, Granzin M, Schrod J: Testing mobile air purifiers in a school classroom: Reducing the airborne transmission risk for SARS-CoV-2. Aerosol Science and Technology 2021: 1–14

7. Davies MH, Rosen M, Eccles JD, Marshal RJ: Criteria of air flow and negative pressure for high volume dental suction. Br Dent J 1971; 130: 483–7

8. Day CJ, Sandy JR, Ireland AJ: Aerosols and splatter in dentistry – a neglected menace? Dent Update 2006; 33: 601–2, 604–6

9. Duguid, J.P.: The size and the duration of air-carriage of respiratory droplets and droplet-nuclei. J Hyg (Lond) 1946; 44: 471–9

10. Estrich CG, Mikkelsen M, Morrissey R et al.: Estimating COVID-19 prevalence and infection control practices among US dentists. J Am Dent Assoc 2020; 151: 815–824

11. Exner M, Walger P, Gebel J, Schmithausen R, Kramer A, Engelhart S: Zum Einsatz von dezentralen mobilen Luftreinigungsgeräten im Rahmen der Prävention von COVID-19. In: Stellungnahme der Deutschen Gesellschaft für Krankenhaushygiene (DGKH) vom 25.09.2020, DGKH, Editor. 2020: https://www.krankenhaushygiene.de/ccUpload/upload/files/2020_09_03_DGKH_Stellungnahme_Zum_Einsatz_von_dezentralen_Luftreinigern_zur_Praevention.pdf (Abgerufen 09.07.2021)

12. Fitzner K, Finke U: Lüftungsregeln für freie Lüftung. Bundesanstalt für Arbeitsschutz und Arbeitsmedizin 2012: 1–89 https://www.baua.de/DE/Angebote/Publikationen/Berichte/F2072.pdf?__blob=publicationFile&v=1 (Abgerufen 09.07.2021)

13. Ge ZY, Yang LM, Xia JJ, Fu XH, Zhang YZ: Possible aerosol transmission of COVID-19 and special precautions in dentistry. J Zhejiang Univ Sci B 2020; 21: 361–368

14. Graetz C, Bielfeldt J, Tillner A, Plaumann A, Dorfer CE: Spatter contamination in dental practices – how can it be prevented? Rev Med Chir Soc Med Nat Iaşi 2014; 118: 1122–34

15. Graetz C, Düffert P, Heidenreich R, Seidel M, Dörfer CE: The efficacy of an extraoral scavenging device on reducing aerosol particles </= 5 microm during dental aerosol-generating procedures: an exploratory pilot study in a university setting. BDJ Open 2021; 7: 19

16. Innes N, Johnson IG, Al-Yaseen W et al.: A systematic review of droplet and aerosol generation in dentistry. J Dent 2021; 105: 103556

17. Ishihama K, Koizumi H, Wada T et al.: Evidence of aerosolised floating blood mist during oral surgery. J Hosp Infect 2009; 71: 359–64

18. Kähler C, Fuchs T, Hain R: Können mobile Raumluftreiniger eine indirekte SARS-CoV-2 Infektionsgefahr durch Aerosole wirksam reduzieren? 2020

19. Kienbaum T: Hygienemanagement in Gesundheitseinrichtungen – Teil 4: Effektives Lüften während der Pandemie. HYGIENEMANAGEMENT 2020; 10: 47–55

20. Koch M, Graetz C: Spray mist reduction by means of a high-volume evacuation system-Results of an experimental study. PLoS One. 2021;16(9):e0257137.

21. Kohn WG, Harte JA, Malvitz DM et al.: Guidelines for infection control in dental health care settings – 2003. J Am Dent Assoc 2004; 135: 33–47

22. Kun-Szabo F, Gheorghita D, Ajtai T et al.: Aerosol generation and control in the dental operatory: An in vitro spectrometric study of typical clinical setups. PLoS One 2021; 16: e0246543

23. Lewis D: Is the coronavirus airborne? Experts can't agree. Nature 2020; 580: 175

24. Meethil AP, Saraswat S, Chaudhary PP, Dabdoub SM, Kumar PS: Sources of SARS-CoV-2 and other microorganisms in dental aerosols. J Dent Res 2021: 220345211015948

25. Meng L, Hua F, Bian Z: Coronavirus Disease 2019 (COVID-19): emerging and future challenges for dental and oral medicine. Journal of Dental Research; 0: 0022034520914246

26. Mittmann-Frank M, Berger H, Rupf S et al.: Exposition gegenüber Nanopartikeln und neuen Materialien in der Zahnheilkunde. Zentralbl Arbeitsmed Arbeitssch Erg. 2011; 61: 40–53

27. Morawska L, Tang JW, Bahnfleth W et al.: How can airborne transmission of COVID-19 indoors be minimised? Environ Int 2020; 142: 105832

28. Müller LK, Heider J, Frankenberger R et al.: German guidelines: dealing with aerosol-borne pathogens in dental practices. Dtsch Zahnärztl Z INT 2020; 2: 164–9

29. Nulty A, Lefkaditis C, Zachrisson P, Van Tonder Q, Yar R: A clinical study measuring dental aerosols with and without a high-volume extraction device. Br Dent J 2020

30. Peng X, Xu X, Li Y, Cheng L, Zhou X, Ren B: Transmission routes of 2019-nCoV and controls in dental practice. Int J Oral Sci 2020; 12: 9

31. Polednik B: Exposure of staff to aerosols and bioaerosols in a dental office. Building and Environment 2021; 187: 1–13

32. Reitemeier B, Jatzwauk L, Jesinghaus S, Reitemeier C, Neumann K: Effektive Reduktion des Spraynebel-Rückpralls – Möglichkeiten und Grenzen. ZMK 2010; 26: 662–673

33. Rupf S, Berger H, Buchter A, Harth V, Ong MF, Hannig M: Exposure of patient and dental staff to fine and ultrafine particles from scanning spray. Clin Oral Investig 2015; 19: 823–30

34. Samaranayake LP, Fakhruddin KS, Buranawat B, Panduwawala C: The efficacy of bio-aerosol reducing procedures used in dentistry: a systematic review. Acta Odontol Scand 2021; 79: 69–80

35. Samaranayake LP, Reid J, Evans D: The efficacy of rubber dam isolation in reducing atmospheric bacterial contamination. ASDC J Dent Child 1989; 56: 442–4

36. Shahdad S, Patel T, Hindocha A et al.: The efficacy of an extraoral scavenging device on reduction of splatter contamination during dental aerosol generating procedures: an exploratory study. Br Dent J 2020

37. Stadnytskyi V, Bax CE, Bax A, Anfinrud P: The airborne lifetime of small speech droplets and their potential importance in SARS-CoV-2 transmission. Proc Natl Acad Sci U S A 2020; 117: 11875–11877

38. Szymanska J: Dental bioaerosol as an occupational hazard in a dentist's workplace. Ann Agric Environ Med 2007; 14: 203–7

39. van Doremalen N, Bushmaker T, Morris DH et al.: Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. N Engl J Med 2020; 382: 1564–1567

40. Veena HR, Mahantesha S, Joseph PA, Patil SR, Patil SH: Dissemination of aerosol and splatter during ultrasonic scaling: a pilot study. J Infect Public Health 2015; 8: 260–5

41. Watanabe A, Tamaki N, Yokota K, Matsuyama M, Kokeguchi S: Use of ATP bioluminescence to survey the spread of aerosol and splatter during dental treatments. J Hosp Infect 2018; 99: 303–305.

Photo: C. Graetz

Corresponding author
PROF. DR. CHRISTIAN GRAETZ
Clinic for Dental Conservation and Periodontology
at the University Hospital Schleswig-Holstein
Campus Kiel
Christian.Graetz@uksh.de

DZZ International
German Dental Journal International

Publishing Institution
International Journal of the German Society of Dentistry and Oral Medicine/Deutsche Gesellschaft für Zahn-, Mund- und Kieferheilkunde e.V. (Zentralverein, gegr. 1859), Liesegangstr. 17a, 40211 Düsseldorf, Phone: +49 211 610198-0, Fax: +49 211 610198-11

Affiliations
German Society of Periodontolgy (DG PARO)
German Society for Prosthetic Dentistry and Biomaterials
German Association for Conservative Dentistry
German Society of Craniomandibular Function and Disorders in the DGZMK
German Society of Paediatric Dentistry
German Academy of Oral and Maxillofacial Surgery
German Association of Dento-Maxillo-Facial Radiology (GSDOM)
German Academy of Dental Ergonomics
Group of Basic Science in Dentistry

Publisher
Deutscher Ärzteverlag GmbH
Dieselstr. 2, 50859 Köln;
Postfach 40 02 65, 50832 Köln
Phone: +49 2234 7011-0; Fax: +49 2234 7011-6508
www.aerzteverlag.de

Executive Board
Jürgen Führer, Patric Tongbhoyai

Product Management
Carmen Ohlendorf, Phone: +49 02234 7011-357;
Fax: +49 2234 7011-6357;
ohlendorf@aerzteverlag.de

Editorial Office
Susanne Neumann, Phone: +49 2234 7011-219,
neumann.extern@aerzteverlag.de
Thomas Volmert, Phone: +49 2234 7011-253,
volmert@aerzteverlag.de

Frequency
6 times a year

Layout
Larissa Arts

Account
Deutsche Apotheker- und Ärztebank, Köln,
Kto. 010 1107410 (BLZ 370 606 15),
IBAN: DE 2830 0606 0101 0110 7410,
BIC: DAAEDEDD,
Postbank Köln 192 50–506 (BLZ 370 100 50),
IBAN: DE 8337 0100 5000 1925 0506,
BIC: PBNKDEFF

3. Volume
ISSN 2627-3489