Pilot study on the applicability of boron-doped diamond electrodes for tooth whitening

Virgilia Klär1 | Victor Palarie2 | Andreas Burkovski3 | Matthias Karl1 | Tanja Grobecker-Karl1

1Department of Prosthodontics, Saarland University, Homburg/Saar, Germany
2Laboratory of Tissue Engineering and Cellular Cultures, State University of Medicine and Pharmacy “N. Testemitanu”, Chisinau, Moldova
3Microbiology Division, Department of Biology, University of Erlangen-Nürnberg, Erlangen, Germany

Correspondence
Matthias Karl, Department of Prosthodontics, Saarland University, Kirrberger Strasse 100, 66421 Homburg/Saar, Germany.
Email: matthias.karl@uks.eu

Abstract

Objectives: While various approaches are available for tooth whitening, the basic concept employs the use of peroxides in the form of gels, which are applied to tooth surfaces. Previous studies have shown that reactive oxygen species acting as potent disinfectants can be produced using boron-doped diamond (BDD) electrodes for the electrolysis of water. With these electrodes being applicable, for example, for endodontic treatment, it was the goal of this pilot study to use such electrodes for tooth whitening.

Material and Methods: Two groups (n = 10) of intact clinical crowns were obtained by horizontally cutting off roots of extracted human teeth. The crowns were either bleached by applying a commercially available agent based on 40% hydrogen peroxide or were immersed in saline undergoing electrolysis with BDD electrodes. Whitening of specimens was judged on standardized photographs by examiners with three different levels of experience. Statistical analysis was based on Gwet’s AC2 coefficient with quadratic weights, Shapiro–Wilk tests, and two-way analysis of variance of aligned rank transformed data (level of significance set at α = .05).

Results: Levels of reliability ranging from fair to substantial were recorded for single persons while the level of reliability ranged between fair and moderate for groups of raters. The level of experience had no significant effect on the ratings (p = .2500). The bleaching method had a significant effect on ratings (p = .0005) with BDD electrodes showing less effect.

Conclusions: Bleaching by applying BDD electrodes was possible, but was not as effective as the use of commercially available in-office whitening gel. A potential explanation may be seen in different concentrations of reactive oxygen species.

Keywords
boron-doped diamond electrodes, reactive oxygen species, shade selection, tooth whitening

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2022 The Authors. Clinical and Experimental Dental Research published by John Wiley & Sons Ltd.
1 | INTRODUCTION

Tooth whitening has been described as one of the most noteworthy advancements in esthetic dentistry (Blatz et al., 2019) and has become one of the most requested dental treatments (Rodríguez-Martínez, 2019). Several approaches (Carey, 2014) with respect to materials and application modes such as in-office bleaching, home bleaching (da Rosa et al., 2020) and internal bleaching (Frank et al., 2021) are available (Eppl et al., 2019).

Most whitening systems use varying concentrations (Maran et al., 2020) of hydrogen peroxide as the active ingredient, which is either applied directly or produced in a chemical reaction from carbamide peroxide (Carey, 2014; Frank et al., 2021; Rodríguez-Martínez et al., 2019). The mode of action consists of the oxidation of organic chromophores (Eppl et al., 2019) and the effectiveness seems to depend on factors such as concentration and pH value of the whitening agent, application duration, chemical additives, and remineralizing agents (Alkahtani et al., 2020).

Negative effects of tooth whitening include tooth hypersensitivity (Chen et al., 2021; Eppl et al., 2019; Rodríguez-Martínez et al., 2019; de Sá et al., 2021), and gingival irritation (Carey, 2014), as well as damage of the natural organic matrix of enamel and dentin (Eppl et al., 2019), resulting in reduced microhardness (Ferreira et al., 2021; Yang et al., 2021) and surface roughening (de Sá et al., 2021). A potential explanation for the occurrence of bleaching sensitivity has recently been provided (Chen et al., 2021). According to Chen and co-workers, the penetration of hydrogen peroxide inside the pulp cavity (Bernardi et al., 2021) induces cytotoxicity and pain conduction in dental pulp stem cells via intracellular reactive oxygen species.

In light of these problems associated with current methods of tooth whitening, advanced approaches (Alkahtani et al., 2020) have been developed and tested. These range from the use of lasers (Karanasiou et al., 2021) and ozone (Dietrich et al., 2021) to the application of photosensitizers (Li et al., 2021) and hydrogen peroxide-containing hydrated calcium silicate (Yang et al., 2021).

Being aware of the ability of boron-doped diamond (BDD) electrodes to produce various reactive oxygen species during the electrolysis of water, their use might also be an option for developing a well-controllable bleaching method. Previous work has shown that such electrodes may be applied for disinfecting dental implants (Koch, Burkovski, et al., 2020; Koch, Göltz, et al., 2020) and root surfaces and root canals (Böhm et al., 2019).

Given the similarity of the peroxides produced during electrolysis and commercially available bleaching agents, it was the goal of this in vitro study to compare a standard in-office bleaching system with electrochemical bleaching using BDD electrodes.

2 | MATERIALS AND METHODS

Following extraction, teeth were stored in formalin and roots were removed by horizontal cutting using a diamond band saw (EXAKT 300; EXAKT Advanced Technologies GmbH, Norderstedt, Germany). The crowns were not cleaned and split into two groups (n = 10) by an independent person not familiar with the study design. In the control group (OPAL), a chemically activated in-office bleaching system based on 40% hydrogen peroxide (Opalescence Boost; Ultradent Products, Cologne, Germany) was applied for 20 min. In the test group (BDD), specimens were immersed in 1.5 ml 0.67 M NaCl solution and covered before starting electrolysis with a BDD electrode (Figure 1) for 20 min. The electrode was attached to a laboratory power supply set at 5.5–7.5 V and 50 mA.

Before the bleaching procedure, visual shade selection (Czigola et al., 2021) was done by an experienced clinician using the VITA classical A1–D4 shade guide (VITA Zahnfabrik H. Rauter, Bad Säckingen, Germany). Using a white backdrop, standardized photographs of the crowns were taken at a distance of 30 cm before and after bleaching with the previously selected shade depicted as reference (Klinke et al., 2021; Preethi Suganya et al., 2020). The digital camera (Nikon D90; Nikon Europe, Amsterdam, Netherlands) equipped with an objective lens (AF-S VR Micro-NIKKOR 105 mm; Nikon Europe) was set at 125/F40 and the flash (Speedlight SB-29s; Nikon Europe) was set at M1/4.

The pictures were shown as a combination of before and after bleaching as well as with the shade selected before bleaching (Figure 2). The photographs were presented to the examiners on a television screen in three series, each with a randomized order of samples. Judgment was done during a single session with each examiner who was asked to judge the bleaching result as 0 (no bleaching), 1 (low bleaching effect), 2 (medium bleaching effect), and 3 (high bleaching effect). The single raters represented different levels of experience (groups) and consisted of final year dental students, dental assistants, and dentists with three representatives in each group.
Statistical analysis included intrarater agreement of single raters and intrarater agreement within groups applying Gwet’s AC2 coefficient with quadratic weights (Gwet, 2014). Comparisons between the groups of raters as well as comparisons between the bleaching methods were based on Shapiro–Wilk tests and two-way analysis of variance of aligned rank transformed data (Wobbrock et al., 2011). All calculations were done using the R software package (R, The R Foundation for Statistical Computing, Vienna, Austria; www.R-project.org) with the level of significance set at $\alpha = .05$.

### RESULTS

The mean rating values in each group of judges ranged from 2.700 to 3.600 for samples bleached using BDD electrodes while values between 4.333 and 4.900 were recorded following in-office bleaching (Table 1).

The ratings provided by the single judges showed levels of reliability ranging from fair to substantial according to the Landis–Koch scale (Table 2a). In the group of dentists, the ratings provided by two individuals did not significantly differ from random scoring ($p = .1830$ and $p = .1312$). Considering the three groups of raters (Table 2b), the level of reliability ranged from fair to moderate, with both dentists’ and assistants’ ratings not significantly differing from random scoring ($p = .1830$ and $p = .1312$).

The Shapiro–Wilk test indicated a nonnormal distribution of measurement values ($p < .0001$). Consequently, analysis of variance of aligned rank transformed data was applied using group (Student, Dentist, Assistant) and method (BDD, OPAL) as fixed factors, while rating constituted the variable in the model (Table 3). Neither the factor group nor the interaction group method had a significant effect on the ratings, whereas the bleaching method had a significant effect on ratings ($p = .0005$).

### DISCUSSION

This pilot in vitro study was aimed at evaluating the possibility of using BDD electrodes for in-office tooth whitening procedures. While the technology is still far from clinical application, a handheld device may be envisaged, which allows for the selective whitening of single teeth using applicators similar to current caries infiltration devices.

A bleaching effect of BDD electrodes as used in this study was present, but was significantly lower as compared to a commercially available, chemically activated in-office bleaching system. In both treatment groups, specimens were exposed to the bleaching agent only once for 20 min, while in clinical situations, multiple treatment cycles would be applicable (Youssef, 2021). It may therefore be argued that the concentration of reactive oxygen species responsible for the whitening effect was lower in the group using BDD electrodes (Maran et al., 2020).

The primary goal of this study was to evaluate the potential of BDD electrodes for tooth whitening in a simplistic in vitro setup.

| Table 1 | Mean values and standard deviations of summed up ratings recorded for the two different bleaching methods. |
|---------|-----------------------------------------------------------------------------------------------------------|
| Group   | BDD Mean | SD  | OPAL Mean | SD  |
| Student | 3.600    | 2.634 | 4.900 | 2.746 |
| Dentist | 2.833    | 2.465 | 4.333 | 2.644 |
| Assistant | 2.700 | 2.200 | 4.500 | 2.910 |
resulting in several limitations that had to be accepted. The raters recruited for this study obviously acted on different scales reaching only low levels of intrarater agreement on a personal as well as on a group level. Despite that, all raters unanimously judged BDD electrodes as being less effective in bleaching as compared to commercial in-office products.

Besides the in vitro (Kwon et al., 2020) nature of this pilot study, several limitations have to be kept in mind when interpreting the findings of this experiment. The ultimate test for a novel tooth whitening method would of course be to conduct a clinical study that, however, is not possible in the current status due to regulatory reasons. Teeth were not mechanically cleaned before bleaching as would be done in a clinical situation applying dentifrice (Ortega-Moncayo et al., 2021) or enamel microabrasion (Bernardi et al., 2021). In addition, specimens were randomly allocated to the two study groups without performing any matching with respect to tooth shade and tooth type.

The shade selection method applied here may be seen ambiguously as it has been described not to lead to consistent results (Czigola et al., 2021). In a clinical situation, the surrounding of a tooth, that is, hard and soft tissues affect the appearance of a specific tooth and subjective judgment is also affected by various factors such as skin color, lighting conditions (Revilla-León et al., 2021), and viewing distance (Klinke et al., 2021). For standardization purposes, it appeared to be best to use a uniform white backdrop for taking pictures, which were repeatedly presented under standardized lighting conditions. A confounder may be seen in the fact that teeth were shown at high magnification as compared to a true-scale clinical situation.

The use of a digital spectrophotometer (e.g., VITA Easyshade V; VITA Zahnfabrik H. Rauter, Bad Säckingen, Germany) or an intraoral scanning device (TRIOS 4; 3Shape A/S, Copenhagen, Denmark) would have been an alternative for objective shade determination.
While these advanced shade selection methods unanimously are described as being more precise, the clinical relevance of such measurements has been questioned in a recent meta-analysis as these may be too sensitive and differences recorded with such instruments may not be detectable by the unaided human eye (da Rosa et al., 2020).

**ACKNOWLEDGMENTS**

The support of O. Gez, U. Körner, K. John, cand. med. dent. M. Neuner, cand. med. dent. C. Erbel, Dr. C. Steiner, Dr. S. Schneider, and Dr. K. Orujov in judging the samples is greatly acknowledged. M. Neuner, cand. med. dent. C. Erbel, Dr. C. Steiner, Dr. S. Schneider, and M. Zulla and L. Hegemann, Division of Hard Coatings, Department of Material Sciences, University of Erlangen-Nuremberg and M. Zulla and L. Hegemann, Division of Ulta-Hard Coatings, Department of Material Sciences, University of Erlangen-Nuremberg, are acknowledged for fabricating the electrodes used in this study. The authors wish to thank Friedrich Graef, Professor emeritus, Department of Mathematics, University of Erlangen-Nuremberg for statistical data analysis. We acknowledge support from the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) and Saarland University within the funding program Open Access Publishing. Open Access funding enabled and organized by Projekt DEAL.

**CONFLICT OF INTEREST**

The author Matthias Karl reports a conflict of interest as the inventor of the boron-doped diamond electrodes used here.

**DATA AVAILABILITY STATEMENT**

Research data are not shared.

**ORCID**

Matthias Karl [http://orcid.org/0000-0002-8748-1024](http://orcid.org/0000-0002-8748-1024)

**REFERENCES**

Alkahtani, R., Stone, S., German, M., & Waterhouse, P. (2020). A review on dental whitening. *Journal of Dentistry*, 100, 103423.

Bernardi, L. G., Favoreto, M. W., de Souza Carneiro, T., Borges, C. P. F., Pulido, C., & Loguercio, A. D. (2021). Effects of microabrasion association to at-home bleaching on hydrogen peroxide penetration and color change. *Journal of Esthetic and Restorative Dentistry*, 34, 335–341. [https://doi.org/10.1111/jerd.12830](https://doi.org/10.1111/jerd.12830)

Blatz, M. B., Chiche, G., Bahat, O., Roblee, R., Coachman, C., & Heymann, H. O. (2019). Evolution of aesthetic dentistry. *Journal of Dental Research*, 98(12), 1294–1304.

Böhm, A. L., Koch, M., Rosiwal, S., Burkovski, A., Karl, M., & Grobecker-Karl, T. (2019). Electrochemical disinfection of experimentally infected teeth by boron-doped diamond electrode treatment. *Journal of Clinical Medicine*, 8(12), E2037.

Carey, C. M. (2014). Tooth whitening: What we now know. *The Journal of Evidence Based Dental Practice*, 14(Suppl), 70–76. [https://doi.org/10.1016/j.jebdp.2014.02.006](https://doi.org/10.1016/j.jebdp.2014.02.006)

Chen, C., Huang, X., Zhu, W., Ding, C., Huang, P., & Li, R. (2021). H2O2 gel bleaching induces cytotoxicity and pain conduction in dental pulp stem cells via intracellular reactive oxygen species on enamel/dentin disc. *PLoS One*, 16(9), e0257221. [https://doi.org/10.1371/journal.pone.0257221](https://doi.org/10.1371/journal.pone.0257221)

Czigola, A., Róth, I., Vitai, V., Fehér, D., Hermann, P., & Borbély, J. (2021). Comparing the effectiveness of shade measurement by intraoral scanner, digital spectrophotometer, and visual shade assessment. *Journal of Esthetic and Restorative Dentistry*, 33(8), 1166–1174.

Dietrich, L., de Assis Costa, M. D. M., Blumenberg, C., Nascimento, G. G., Paranhos, L. R., & da Silva, G. R. (2021). A meta-analysis of ozone effect on tooth bleaching. *Scientific Reports*, 11(1), 13177.

Epple, M., Meyer, F., & Enax, J. (2019). A critical review of modern concepts for teeth whitening. *Dental Journal*, 73(1), 79.

Ferreira, A. C., Batista, A. L., Neto, J. A., Simões, T. M., da Silva, M. G., de Barros, D. D., Catão, J. S., de Oliveira, T. A., & Catão, M. V. (2021). Evaluation of dental enamel microproperties after bleaching with 35% hydrogen peroxide and different light sources: An in vitro study. *Journal of Clinical and Experimental Dentistry*, 13(10), e969–e974.

Frank, A. C., Kanzow, P., Rödig, T., & Wiegand, A. (2021). Comparison of the bleaching efficacy of different agents used for internal bleaching—A systematic review and meta-analysis. *Journal of Endodontics*, 48, S0099–S2399. [https://doi.org/10.1016/j.joen.2021.011](https://doi.org/10.1016/j.joen.2021.011)

Gwet, K. L. (2014). *Handbook of inter-rater reliability* (4th ed.). Advanced Analytics LLC.

Karanaisou, C., Dionysopoulos, D., Naka, O., Strakas, D., & Tolidis, K. (2021). Effects of tooth bleaching protocols assisted by Er:Cr:YSGG and diode (980 nm) lasers on color change of resin-based restoratives. *Journal of Esthetic and Restorative Dentistry*, 33(8), 1210–1220.

Klinke, T., Bratner, S., Hannak, W., Boening, K., & Jakstät, H. (2021). Influence of viewing distance on visual color differentiation in vitro. *The International Journal of Prosthodontics*. [https://doi.org/10.11607/ijp.7115](https://doi.org/10.11607/ijp.7115)

Koch, M., Burkovski, A., Zulla, M., Rosiwal, S., Geißdörfer, W., Dittmar, R., & Grobecker-Karl, T. (2020). Pilot study on the use of a laser structured double diamond electrode (DDE) for biofilm removal from dental implant surfaces. *Journal of Clinical Medicine*, 9(1), E3036.

Koch, M., Gölitz, M., Xiangjun, M., Karl, M., Rosiwal, S., & Burkovski, A. (2020). Electrochemical disinfection of dental implants experimentally contaminated with microorganisms as a model for periimplantitis. *Journal of Clinical Medicine*, 9(2), E475.

Kwon, S. R., Cortez, E., Wang, M., Jagwani, M., Oyono, U., & Li, Y. (2020). Systematic review of in vitro studies evaluating tooth bleaching efficacy. *American Journal of Dentistry*, 33(1), 17–24.

Li, Z., Wu, Z., Wang, J., Huang, M., & Lin, M. (2021). Expanding the applications of photodynamic therapy-tooth bleaching. *Clinical Oral Investigations*, 26, 2175–2186. [https://doi.org/10.1007/s00784-021-04199-7](https://doi.org/10.1007/s00784-021-04199-7)

Maran, O. N., Amadori, A. L., Loguercio, A. D., Reis, A., & Berger, S. B. (2020). In-office bleaching with low/medium vs. high concentrate hydrogen peroxide: A systematic review and meta-analysis. *Journal of Dentistry*, 103, 103499. [https://doi.org/10.1016/j.jdent.2020.103499](https://doi.org/10.1016/j.jdent.2020.103499)

Ortega-Moncayo, M. G., Aliaga-Sancho, P., Pulido, C., Gutierrez, M. F., Rodriguez-Salazar, E., Burey, A., León, K., Román-Oñate, Y.,
Galvao Arrais, C. A., Loguercio, A. D., & Dávila-Sánchez, A. (2021). Is the use of a potassium nitrate dentifrice effective in reducing tooth sensitivity related to in-office bleaching? A randomized triple-blind clinical trial. Journal of Esthetic and Restorative Dentistry, https://doi.org/10.1111/jerd.12826

Preethi Suganya, S., Manimaran, P., Saisadan, D., Dhinesh Kumar, C., Abirami, D., & Monnica, V. (2020). Spectrophotometric evaluation of shade selection with digital and visual methods. Journal of Pharmacy and BioAllied Sciences, 12(Suppl 1), S319–S323.

Revilla-León, M., Methani, M. M., & Özcan, M. (2021). Impact of the ambient light illuminance conditions on the shade matching capabilities of an intraoral scanner. Journal of Esthetic and Restorative Dentistry, 33(6), 906–912.

Rodríguez-Martínez, J., Valiente, M., & Sánchez-Martín, M. J. (2019). Tooth whitening: From the established treatments to novel approaches to prevent side effects. Journal of Esthetic and Restorative Dentistry, 31(5), 431–440.

da Rosa, G., Maran, B. M., Schmitt, V. L., Loguercio, A. D., Reis, A., & Naufel, F. S. (2020). Effectiveness of whitening strips use compared with supervised dental bleaching: A systematic review and meta-analysis. Operative Dentistry, 45(6), E289–E307.

de Sá, J. L., Silva, J. S., Herkraft, F. J., Favoretto, M. W., Reis, A., Silva, L. M., Loguercio, A. D., & Martins, L. M. (2021). In-office bleaching with complete cervical third protection protocol: A split-mouth, double-blind, randomized clinical trial. American Journal of Dentistry, 34(5), 281–285.

Tabatabaian, F., Beyabanaki, E., Alirezaei, P., & Epakchi, S. (2021). Visual and digital tooth shade selection methods, related effective factors and conditions, and their accuracy and precision: A literature review. Journal of Esthetic and Restorative Dentistry. 33(8), 1084–1104. https://doi.org/10.1111/jerd.12816

Wobbrock, J. O., Findlater, L., Gergle, D., & Higgins, J. J. (2011). The aligned rank transform for nonparametric factorial analyses using only ANOVA procedures. Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI 2011), Vancouver, British Columbia (May 7–12, 2011) (pp. 143–146). ACM Press.

Yang, S. Y., Choi, J. W., Kim, K. M., & Kwon, J. S. (2021). Effects of 35% hydrogen peroxide solution containing hydrated calcium silicate on enamel surface. Clinical Oral Investigations, 26, 2133–2142. https://doi.org/10.1007/s00784-021-04194-y

Youssef, S. A., Cunha, S. R., Mayer-Santos, E., Brito, S. A., de Freitas, P. M., Ramalho, J., Morimoto, S., Gonçalves, F., & Ramalho, K. M. (2021). Influence of 35% hydrogen peroxide gel renewal on color change during in-office dental photobleaching with violet LED: A split-mouth randomized controlled clinical trial. Photodiagnosis and Photodynamic Therapy, 36, 102509.

How to cite this article: Klär, V., Palarie, V., Burkovski, A., Karl, M., & Grobecker-Karl, T. (2022). Pilot study on the applicability of boron-doped diamond electrodes for tooth whitening. Clinical and Experimental Dental Research, 8, 757–762. https://doi.org/10.1002/cre2.586