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Introduction of a new teaching concept for dentin post preparation with 3D printed teeth

Christian Höhne | Nora Dickhaut | Marc Schmitter

Department of Prosthodontics, University of Würzburg, Würzburg, Germany

Correspondence
Christian Höhne, Department of Prosthodontics, University of Würzburg, Pleicherwall 2, 97070 Würzburg, Germany.
Email: hoehne_c@ukw.de

Abstract

Introduction: The preparation for dentin posts is difficult and hard to learn. There are currently no reproducible simulation models to train this clinical procedure. The purpose of this study was the design, feasibility and evaluation of a three-dimensional (3D) printed tooth model for the pre-clinical teaching of students.

Materials and methods: A printable tooth was designed and printed by a stereolithographic printer. A total of 48 fourth-year dental students in the first clinical course in prosthodontics were trained in a voluntary hands-on course on 4 similar printed teeth. The students used standard model teeth and real-teeth models during their education. They had experience in caries removement and root canal treatment on real patients. Root perforations were counted for every attempt. The different benefits of the 3D printed tooth were evaluated by a questionnaire using German school grades from 1 (best) to 6 (worst).

Results: The overall rating of the printed tooth was Ø1.9 ± 0.3. The item "suitable exercise option" was rated Ø2.0 ± 0.8, and the teeth were "easy to use" Ø1.9 ± 0.9. The item "realistic approach to dentin post preparation" was rated Ø2.1 ± 0.8, and the teeth showed the "shortcomings at a root perforation" Ø1.5 ± 0.6. The students reported to have much more motivation and enthusiasm to improve their skills with the printed teeth Ø2.1 ± 0.9. They had a strong desire to include these teeth in their pre-clinical education before the first patient treatment Ø1.6 ± 0.8. The success rate of the dentin post preparation was significantly better for the second 25% ($P = .047$) and fourth 48% ($P = .04$) attempt.

Conclusions: The feasibility of this teaching concept was confirmed. The students had the possibility to learn a correct dentin post preparation on a printed tooth model. The learning effect with this tooth model was rated as good to very good by the questionnaire.

KEYWORDS

3D printing, additive manufacturing, CAD, CAM, clinical practice, dental education, dentin post, printed tooth, rapid prototyping, stereolithography, student training

1 | INTRODUCTION

New three-dimensional (3D) printing technologies give us already the chance to produce individual teeth models with more anatomical characteristics. In combination with micro-computed tomography (µCT), the reconstruction of complex root canal systems can be used for dental education.[1] The main problem for the creation of 3D printed models for dental education was the characteristics of the printing materials, which were initially designed for visual models for the industry. However, today there are new materials available for 3D printers with more usable properties.[2] They enable us to produce functional and individual teeth models at very low cost. Despite these new possibilities, there are only very simple teeth models available for the education of students in important treatment options. Thus, the training of the management of clinical conditions during pre-clinical education is neglected, postponing this problem to the clinical education. One of the clinical challenges is the preparation of a decayed tooth for a dentin post. The preparation for a dentin post can be very complicated and risky. Students have no chance to train such a situation on a realistic model so far. Therefore, the challenge is to combine 3D printing technology and µCT to reconstruct realistic tooth morphology for dental education.

The basic methodology for the creation of 3D models based on µCTs was described by Kato et al.[1] The µCT data were used for the reconstruction of the enamel, dentin and pulp of different teeth, and an online database for 3D models was created. They proposed the great advantages of such models to study the dental morphology and phylogeny.

Even a CT with a lower resolution can be used for a precise reconstruction. Hannig et al[3] described the reconstruction of human teeth with a flat panel-based volume CT (fpVCT) with a resolution of 150 µm. They reported that the fpVCT can be used for non-destructive volumetry of large numbers of teeth in experimental laboratory studies.

It is well described that a visual recognition and haptic feedback at the learning process has great effects on the student's performance. Soares et al[4] used 3D printed models and virtual models to demonstrate the differences in cavity preparation for teaching students. They described a positive learning effect for the students and teachers.

Kröger et al[5] used 3D printed models, based on real patients, for the training of students in different treatment situations. Three different models were used in the study. The first model was for veneer preparation, the second was for dental bonding, and the third was for interdisciplinary simulation of caries excavation and crown removement. The different models were evaluated by students in a questionnaire and received a good feedback.

Cantin et al[6] created 3D printable models to study the morphology of permanent teeth. The production process of the models was described and a very important role in the teaching of tooth anatomy for dental students expected.

We introduced two other printed tooth models. With the first model, students had the opportunity to practice a complete treatment of a prosthodontic situation. This included caries excavation, pulp capping, core build-up and crown preparation. Each step of the process was controllable with a blue LED light.[7] The second printed tooth model was for teaching a crown preparation with different material properties in hardness and colour for enamel and dentin. Also, a realistic pulp was simulated and a printed teaching model was included.[8]

The aim of this study was to design, establish and test the feasibility of a 3D printed tooth used for a dentin post preparation. The benefits for education were evaluated by a questionnaire.

We hypothesised that the use of a 3D printed tooth model for dentin post preparation has a positive impact on the educational experience of pre-doctoral dental students.

2 | MATERIALS AND METHODS

The study was approved by the Institutional Review Board, which is the ethics committee of the university and received an exemption.

2.1 | Design of the printed tooth

The tooth was designed based on a micro-CT scan of an extracted lower left first molar. The data were acquired by a MetRIC (Micro and region of interest CT) with a resolution of 2 microns. This micro-CT was manufactured by the "Frauenhofer-Institut für Integrierte Schaltungen" (Frauenhofer IIS, Erlangen, Germany). The 3D reconstruction of the tooth was separated into the tooth and the pulp (Figure 1A,C). A standard dental study model (KaVo, Biberach an der Riß) was scanned by an InEos X5 scanner (Dentsply Sirona, York, Pennsylvania, USA). The tooth was designed (Figure 2A) based on the micro-CT and the scan of the study model with Autodesk Inventor 2019 (Autodesk, San Rafael, USA). The tooth and the pulp were converted into a solid body, and the crown was cut off to simulate a deep decayed tooth (Figure 1D). After this, the constructed tooth was connected to the tooth holder of the standard dental study model (Figure 2A) and was surrounded at the upper part with a ring for stabilisation in the study model. Based on the anatomy of the pulp, an ideal root canal preparation was designed. The geometries of the preparation were similar to the preparation done by the Reciproc Blue R25 file system (VDW, Munich, Germany). The root canal was filled after this with compatible guttapercha master points (VDW) displayed in orange (Figure 2B). The printed tooth was ready now for the dentin post treatment. An ideal dentin post preparation was simulated for a cast post ER-System (Komet, Lemgo, Germany) in the distal root. A 9 mm long and 2.1° conical post was inserted (Figure 2C). The width of the post was 0.9 mm at the apex, and guttapercha filling was left 3 mm apically. An X-ray of the tooth was designed using a look through image from the CAD model. This image was modified with GIMP 2.10.10 (GNU General Public License) using different filters to mimic a radiograph. The close relationship to the outer wall of the tooth can be seen in Figure 2D. This anatomical

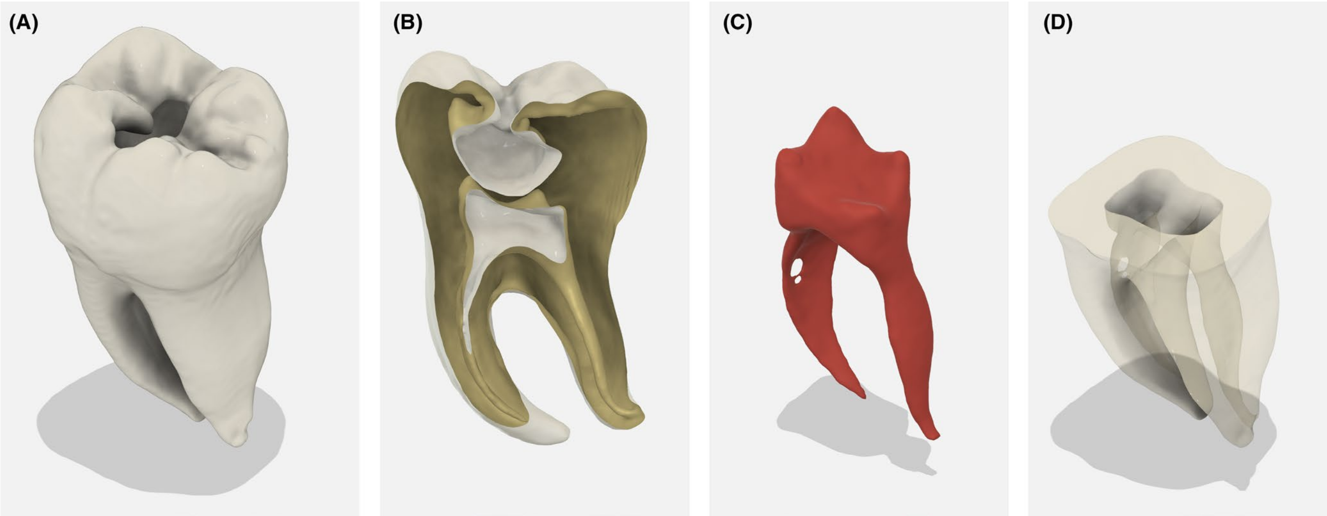

FIGURE 1 The three-dimensional model after the segmentation of the micro-computed tomography scan (A); a cross section of the tooth, the deep carious lesion, the pulp and the root channels are visible (B); the segmentation of the pulp (C); and transparent look into the tooth model with the pulp after the conversion to a solid body and cut of the crown (D) [Colour figure can be viewed at wileyonlinelibrary.com]

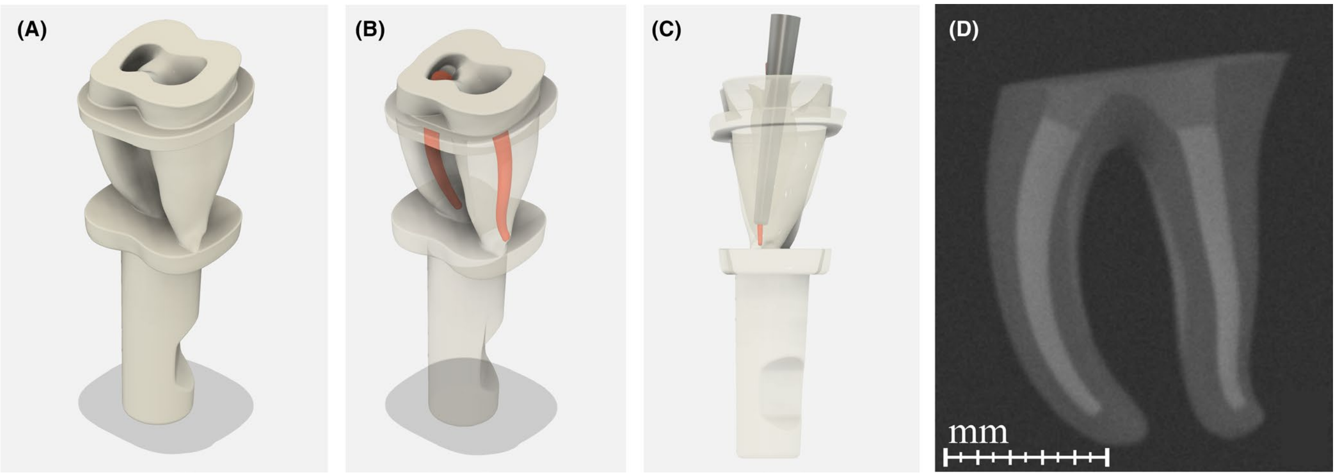

FIGURE 2 The tooth adapted for the dental study model (A); construction of an ideal root canal preparation and filling (B); construction of an ideal fitting dentin post (C); and the designed radiograph of the tooth with visible root canal filling (D) [Colour figure can be viewed at wileyonlinelibrary.com]

proximity can represent a challenging situation that has to be overcome by the student during their exercise in correcting the preparation axis.

2.2 | Production of the teeth

After the computer-aided design (CAD) with Autodesk Inventor 2019 (Autodesk), the tooth was imported into PreForm 3.0.1 (Formlabs Inc, Somerville, Massachusetts, USA) as a Wavefront OBJ-file (OBJ) and prepared for 3D printing in a Form2 3D printer (Formlabs Inc). White photopolymer resin (RS-F2-GPWH-04, Formlabs Inc) was used for the print of the tooth. The teeth were washed after the production with 95% isopropanol for 20 minutes in the Form Wash unit (Formlabs Inc) and cured for 1 hour in the Form Cure unit (Formlabs Inc).

2.3 | Completion of the teeth after print

Afterwards, both root canals were filled with guttapercha master points for the Reciproc Blue R25 file system (VDW) spreaded with AH plus sealer (Dentsply De Trey GmbH, Konstanz, Germany). The printing supports were removed, and the tooth was completed (Figure 3A).

2.4 | Training on the tooth model

In total, n = 48 fourth-year dental students (at a school with a 5 year dental programme) participated in a voluntary hands-on course. They were all in the first clinical course in prosthodontics. The students (35 females and 13 males, from 22 to 32 year with a mean age of 25) were

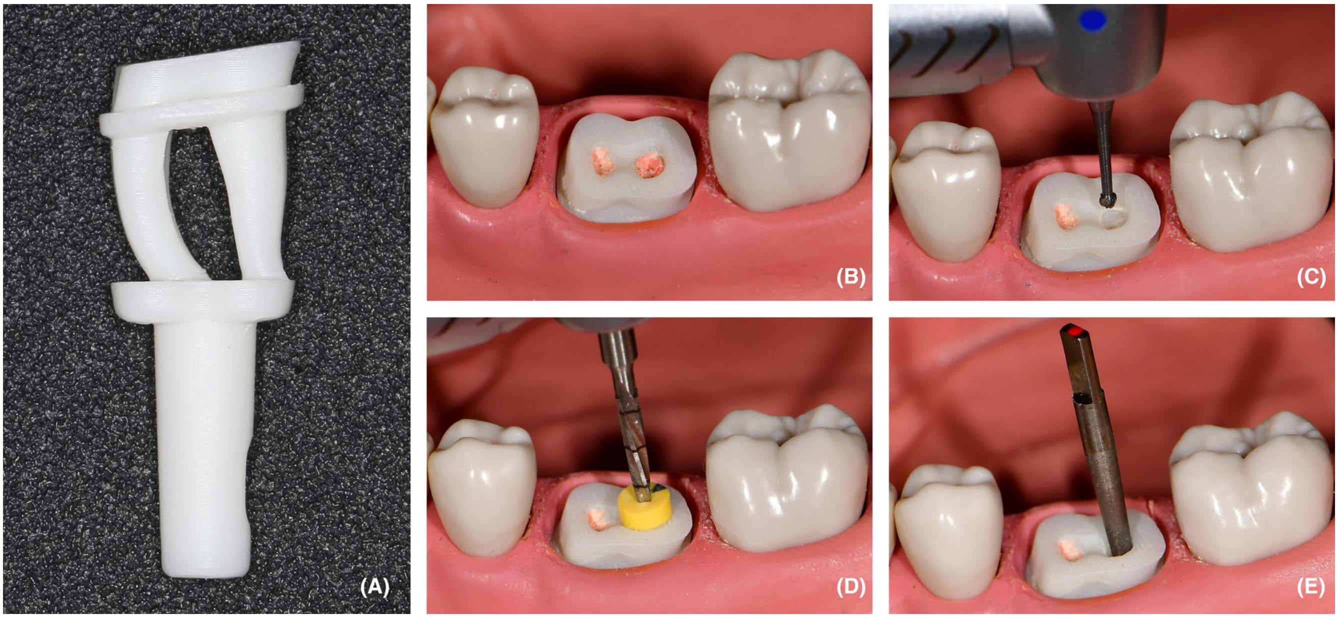

FIGURE 3 The printed tooth after the completed production process (A); the printed tooth in the study model with visible guttapercha filling (B); partial removement of the guttapercha by a round burr (C), the preparation for the dentin post (D); and control of the final preparation by a dentin post (E) [Colour figure can be viewed at wileyonlinelibrary.com]

trained on n = 192 printed teeth. They were familiar with the preparation of standardised artificial model teeth. These teeth were used during their pre-clinical education. The participating students were experienced in patient treatment and had also experience on real-teeth models. They had done at least 10 dental fillings and three endodontic treatments on patients on their own. Every student had the opportunity to prepare dentin posts for four identical printed teeth. The students mounted the printed tooth into their study model (Figure 3B). At the first step, the students removed one third of the guttapercha filling with a round burr (Figure 3C) to get access for the first drill of the cast post ER-System (Komet). The preparation for the dentin post was now done with two drills with different dimensions (Figure 3D), and the final preparation was controlled by a red cast post (ER-System, Komet). The students had the chance to visually control their preparation by removing the printed tooth at any time. Therefore, the students were able to check for perforations and to control the orientation of the axis. After the completion of the root preparation, every tooth was controlled. The root perforations were displayed in Figure 5.

2.5 | Questionnaire after practice

The benefits of the 3D printed tooth were evaluated by the 48 students using an online questionnaire (Table 1). The printed teeth were compared with real teeth. The evaluation was generated with EvaSys (Electric Paper Evaluationsssysteme GmbH, Lüneburg, Germany) by the "Institute for Medical Teaching and Medical Educational Research" of the university. The questionnaire was already tested in a course in endodontic treatment and three printed tooth models.[7,8] This questionnaire was also used for this 3D printed tooth. At the end of the training, every student received a single key for the digital questionnaire. The questions were designed as closed format rating scale questions divided into German school grades (1 = excellent, 2 = good, 3 = satisfactory, 4 = adequate, 5 = poor, 6 = unsatisfactory) for a good discrimination. The last questions were free text questions. The students had to rate the educational effect of the 3D printed teeth and real teeth.

2.6 | Statistical analysis

The overall and the mean grade of every question were calculated and displayed in a bar chart in Figure 4. Also, the standard deviation was calculated. The quantities of given grades were displayed in percentage. For reliability analysis, Cronbach's alpha was calculated. Differences between the attempts of the root preparations (Figure 5) were calculated using a binomial test. Values under $P = .05$ were counted as significant different.

3 | RESULTS

The internal consistency of the questionnaire was high, with a Cronbach's alpha of .85. No significant effect of the age and gender of the participating students was detectable. The printed tooth was evaluated with an overall grade of 1.9 ± 0.3.

3.1 | Production and completion of the teeth

Seventy teeth were produced at one build platform of the printer in 6 hour and 30 minutes. The automated production time of a single

TABLE 1 The questionnaire for the evaluation of the printed tooth

1. Personal data
1.1. Please enter your gender
1.2. Please enter your age
2. Comparison of the printed tooth to a real tooth
2.1. Suitable exercise option
2.2. Easy to use
2.3. High practical relevance
3. Assessment of the learning outcome with the printed tooth
3.1. The printed tooth showed me a realistic approach to dentin post preparation.
3.2. The printed tooth showed me my shortcomings at a root perforation.
4. Assessment of the learning process with the printed tooth
4.1. The printed tooth had filled me with enthusiasm to improve my skills in the preparation of dentin posts.
4.2. In retrospect, I would have liked to practice with the printed teeth before patient treatment.
4.3. The printed tooth helped me to improve my skills in the correct angulation of a dentin post.
4.4. For my studies im interested in more exercises with printed teeth.
5. Free text questions
5.1. What could be improved on the printed teeth?
5.2. Which advantages do you see by using real teeth in dental education?
5.3. Which advantages do you see by using printed teeth in dental education?

tooth was therefore approximately 5.5 minutes. The completion of each tooth was done in approximately 1 minutes. The price for the complete material for one tooth including the working time of a technician was 1.58$. The cost for the printer and the printing equipment was 4440$. Therefore, the production was not expensive and time consuming.

3.2 | Comparison to a real tooth

The results of the comparison of the printed tooth to a real tooth are shown in Figure 4-2. The first question was about the suitability of the tooth for exercise (Figure 4-2.1). The printed tooth was evaluated as good (Ø 2.0 ± 0.8). After that, the use of the printed tooth was assessed (Figure 4-2.2). For the students, the printed tooth was good to use (Ø 1.9 ± 0.9). The last question of the first part of the questionnaire evaluated the practical relevance of the printed teeth (Figure 4-2.3). The comparability to a real situation was evaluated. The students rated the practical relevance of the printed tooth as good to satisfactory (Ø 2.4 ± 0.9).

3.3 | Assessment of the learning outcome

In the next part of the questionnaire, the learning outcome of the students was evaluated for the printed tooth (Figure 4-3). The students felt good prepared (Ø 2.1 ± 0.8) in a realistic approach in dentin post preparation (Figure 4-3.1). The printed tooth showed the students their shortcomings at root perforation (Figure 4-3.2) in a very good to good way (Ø 1.5 ± 0.6).

3.4 | Assessment of the learning process

In the last part of the questionnaire, the learning process of the students was evaluated (Figure 4-4). The students were asked about their interest in improving their skills in tooth preparation with the printed teeth (Figure 4-4.1) and rated the teeth as good (Ø 2.1 ± 0.9). The next question was about the usefulness of printed teeth before real patient treatment (Figure 4-4.2.). The printed teeth achieved a very good to good result (Ø 1.6 ± 0.8). The printed teeth were rated by the students as good (Ø 1.9 ± 0.7) to improve their preparation skills in dentin post preparation (Figure 4-4.3). The students reported (Figure 4-4.4) that they were interested in more exercises with printed teeth (Ø 2.0 ± 1.0).

3.5 | Free text questions

The results of the free text questions of the 48 students were analysed, and similar answers were combined and counted.

3.5.1 | Improvements on the printed teeth

- the hardness of the material was criticised (n = 10)
- request for more models with different canal anatomy (n = 3)
- better fit in the model (n = 3)

3.5.2 | Advantages of real teeth in education

- different hardnesses and colour of the material (n = 12)
- nearly realistic treatment situation (n = 11)
- anatomical differences (n = 3)

3.5.3 | Advantages of the printed teeth in education

- less cost and standardised production in great numbers (n = 12)
- very good and realistic training situation (n = 8)
- availability and hygienical aspects (n = 3)

3.6 | Root perforations

The root perforations of the 48 students were counted for every attempt and were displayed in percentage (Figure 5). A binomial test was calculated between every attempt. The results were significantly

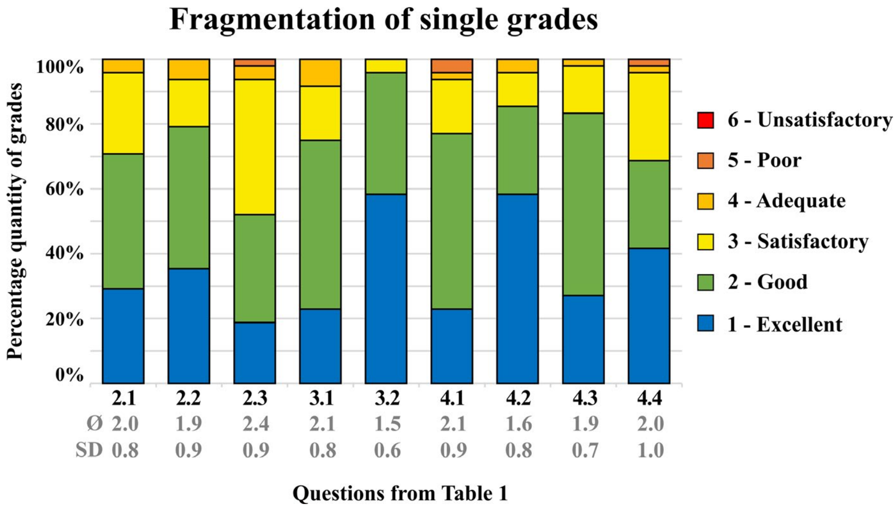

FIGURE 4 The results of the evaluation are visualised as a bar chart. The quantities of given grades are displayed in percentage. The mean values and the standard deviations are under the concerning questions [Colour figure can be viewed at wileyonlinelibrary.com]

different between the first to second and the third to fourth attempt (1-2: $P = .047$; 2-3: $P = .11$; 3-4: $P = .04$). Root perforations occurred at the first attempt 88%, at the second 75%, at the third 69% and at the fourth 52%.

4 | DISCUSSION

With regard to the questionnaire, the concept with the 3D printed teeth for preparation of dentin posts was rated as useful. The answers in the free text section at the end of the questionnaire showed that the students were interested in more teeth with differences in the root canal anatomy (n = 3). Nevertheless, they were also interested to train the dentin post preparation at identical teeth to learn from their mistakes (n = 12). This was achieved at our course and also confirmed by the very good result in the item 3.2 with Ø 1.5 ± 0.6 (Figure 4-3.2.). The students had to evaluate the teaching effect of the model at a root perforation. The production of more teeth with different characteristics is simple after the establishment of the first printed tooth. The full integration process of the printed tooth into a standard dental study model was also described. Another often mentioned point was that the printed tooth helped the students to gain confidence during the preparation of a dentin post. The printed teeth were a very good and realistic training situation (n = 8). This was also verified by the very good result at the item 4.2 with Ø 1.6 ± 0.8 (Figure 4-4.2.). The students had to rate the training with this tooth model before patient treatment. The printed tooth achieved the worst result at question 2.3 with Ø 2.4 ± 0.9 (Figure 4-2.3). The printed tooth was compared to a real tooth at the item "high practical relevance." We think that this was mainly caused by the before mentioned wish for more teeth with different anatomical characteristics. Also, a real tooth is a hard challenge for printed teeth. This was also mentioned in the free text section. A tooth model with natural teeth is a nearly realistic treatment situation (n = 11). The hardness of the printed teeth was criticised (n = 10). New materials for the 3D printer, with optimised material properties (such as hardness), will be introduced soon and may overcome this problem. Also, the fit in the model was criticised (n = 3). This can be caused by differences in the production of the training model and the printed teeth and occurred only in a small number. For a new model, the fit can be easily more enhanced. For this training model, a very difficult situation was selected with an anatomical proximity of the root canal to the outer wall. This challenging situation led to an expectable high count of root perforations at the first attempt with 88%. Even with this small number of trials, a significant learning effect was detectable. The counted root perforations showed a significant difference between the first to second and the third to fourth attempt (1-2: $P = .047$; 3-4: $P = .04$). Root perforations occurred after the training 36% less. It can be assumed that a training with this model increased the quality of post preparation and will enhance the patient safety trough less treatment errors. For the future, more tooth types are planned to train the students in different anatomical situations.

The questionnaire was based on an online questionnaire developed and validated by the institute of "Medical Teaching and Medical

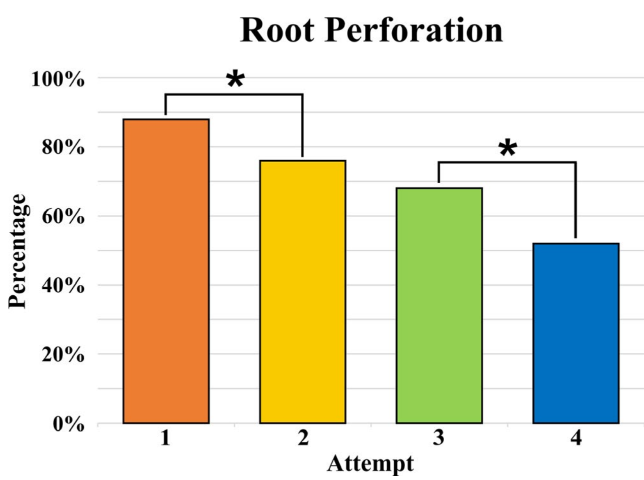

FIGURE 5 The results of the root perforation of the 48 students. The root perforations were counted for every attempt and were displayed in percentage. Significant differences are marked with an asterisk [Colour figure can be viewed at wileyonlinelibrary.com]

Education Research" of the university. This questionnaire was tested with five other printed tooth models. Two of these models are published.[7,8] It was also tested on reliability at a former publication between students and an expert group and proved its consistency.[8]

With our affordable 3D printer (Form2, Formlabs Inc), it is possible to print only one material at one time. There are more sophisticated printers on the market (eg from Stratasys, Rehovot, Israel), which allow to print different materials in one step. Such a printer (Objet 30 Prime, Stratasys) was also available at our department but we had chosen to show this method, which was not cost intensive and would be available to many dental educational institutions. For this type of printed tooth, we see benefits in the finishing process with this printer. The students have the chance to complete the tooth on their own and exercise root canal fillings before the dentin post treatment.

Due to the limitation of this study being conducted at a single dental school, its results may not be generalisable to students in other programmes. However, the hypothesis of this study was confirmed: the 3D printed artificial tooth for the preparation of a dentin post had benefits for education. The questionnaire proved that the root anatomy of a real tooth was mimicked in a good way.

Our plans for the future are the integration of the printed tooth models in our curricula. This will be in the course of the establishment of the new license to practice dentistry in Germany. With the before mentioned printed tooth models, the here described model and projects in the near future, we will have a new teaching concept, which is affordable and will probably enhance the education at our and other universities.

Summarising our results and based on the cheap price of the printing, it is possible to produce all printed teeth for the students. Our introduced model was not expensive (1.58$). Students are using a lot of model teeth during their studies. This was also mentioned by the students in the free text section. They appreciated the cheap price of the printed teeth (n = 12). The price for comparable commercial models is around 5$. But they have no realistic pulp canal and filling. Only the drilling of a straight dentin post is possible. To establish the whole production process, only a single investment in the printing equipment is needed. This was also described and confirmed by Reymus et al[9] They introduced the production of 3D printed replicas for endodontic education with the same 3D printer, we used here.

For the future in dentistry, we expect a great reduction of conventional model teeth and a shift onto individual new teaching concepts. With the help of printed teeth, a lot of different training situations are possible. Furthermore, as mentioned before, they can be produced at very low cost and we think a lot of other dental schools can produce them at no charge for the students.

Only few studies were available on this topic. Boonsiriphant et al[10] described the production process for 3D printed prepared teeth and the use for education of dental students (Printer: Form2, Formlabs Inc). They expected significant advantages for real 3D visual recognition and skill acquisition by students in contrast to two-dimensional (2D) images in books or lectures.

Reymus et al[9] introduced as mentioned before the production of 3D printed replicas for endodontic education. The accuracy of the printer (Printer: Form2, Formlabs Inc) was suitable for the production. The printed teeth were used for root canal preparation and filling. Undergraduate students favoured the availability of these replicas. In our study, the printed teeth were used for the preparation of a dentin post. Reymus et al mentioned also the short-term availability and standardisation of the student training. Another point is the hygienic aspect of extracted teeth for education.

Ordinola-Zapata et al[11] evaluated two file systems on molar replicas (Printer: ProJet HD3500, 3D system, Rock Hill, SC, USA). They found that the two file systems were able to maintain the original shape at the apical third of severely curved mesial canals of molar replicas. This was also investigated by Eken et al[12] with 7 different file systems (Printer: Eden 500 PolyJet, Stratasys). In contrast to our model, they tested the root canal preparation with those instruments but not the preparation for a dentin post. But these publications also confirm that printed teeth are usable for the training of root canal preparation and are close to reality.

Gok et al[13] used printed teeth for the simulation of root canal fillings. They investigated four different canal filling systems. At the apical part of the canal, the cold lateral compaction and cold injectable filling techniques were more successful compared with the warm guttapercha filling techniques. In our study, the students removed the guttapercha with dentin post drills and the root filling was already done.

Another method is the usage of virtual 3D models. This was described by de Boer et al[14-16] with a MOOG Simodent dental trainer® (Moog Dental Simulation, New York, USA). This simulator creates a virtual learning environment with haptic feedback. A positive effect of the simulator on student learning was described. A lot of different patient situations can be simulated. This method is very interesting, and further developments are ongoing. But the method is also very cost intensive because of the simulation devices. Our 3D printed teeth can be produced with less costs and used in standard models without high investments.

5 | CONCLUSION

The feasibility of this teaching model for dentin post preparation was confirmed. The workflow was cost-effective for the production of the teeth with the usage of 3D printing technology. The printed tooth enabled the students to get experience in dentin post preparation on a printed tooth model before patient treatment. The results of the questionnaire showed the great interest of the students in the printed tooth model, and the model was rated as good to very good. This finding was also supported by the significant improvement between the preparations attempts.

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CONFLICT OF INTEREST

The authors have no conflict of interest to disclose.

DATA AVAILABILITY STATEMENT

Data are available on request from the authors.

ORCID

Christian Höhne https://orcid.org/0000-0001-5603-5577

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