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The 3D printed teeth models intended for hands-on practice in conservative dentistry

Katarzyna Dobroś, Justyna Hajto-Bryk, Joanna Zarzecka

Department of Conservative Dentistry with Endodontics, Institute of Dentistry, Faculty of Medicine, Jagiellonian University Medical College, Kraków, Poland

Corresponding author: Katarzyna Dobroś, D.D.S.
Department of Conservative Dentistry with Endodontics, Institute of Dentistry, Faculty of Medicine, Jagiellonian University Medical College
Montelupich 4, 31-155 Kraków, Poland
Phone/fax: +48 (12) 424-54-25; E-mail: katarzyna.dobros@uj.edu.pl

Abstract: Objectives: Designing and printing out a 3D model of a mandible, including the teeth with replicated carious lesions, to be fitted into the Dental Patient Simulator. Students assessed the 3D teeth models against the extracted teeth and the standard models, identifying specific restorative dentistry procedures where they might be applied as the teaching aids.
Methods: A 3D tooth model was printed out against a patient's Cone Beam Computed Tomography scan. The study was attended by 22, 5th-year students, who, having prior removed the caries, filled in the cavities of different classes and trepanned the pulp chamber in the 3D models, subsequently rating them against a questionnaire.
Results: Over 95% of students recommended introducing the 3D models into teaching conservative dentistry with endodontics at the pre-clinical stage to enhance manual skills in cavity preparation and filling. The replication of tissue hardness and anatomical characteristics in the 3D models was rated significantly higher, as compared to the standard ones ($p < 0.05$). Over 90% of students also asserted that working on the 3D models would enhance their pulp chamber trepanation skills, and rated overall replication of the anatomical characteristics significantly higher, in comparison with the standard teeth models ($p < 0.05$).
Conclusions: In pre-clinical education, the 3D teeth models offer a viable alternative, as there is an appreciable potential for different types of teeth to be printed out, in full consideration of their anatomical diversity. Further design refinements in the 3D teeth models are required, though, particularly the ones regarding true-to-life replication of the soft tissues.

Keywords: dental education, teeth, three-dimensional printing.

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Introduction

Caries is a lifestyle disease affecting individuals of all ages [1, 2]. Treatment of carious lesions is a basic skill acquired during dental studies, whereas education of dental students is largely based on practical classes. According to a survey conducted by Schulte *et al.* across 123 dental schools, education in cariology is offered over a period spanning 1 up to 4 years. The majority of schools offer pre-clinical education for 1 year, but about one-third of them ensure 2 years. Clinical education takes place mainly for 2–3 years, although some schools admit to offer this type of education for 1 year only [3].

Whilst attending their pre-clinical classes, the students carry out dental procedures on the standard teeth models, or make use of the extracted teeth. None of those teaching aids are free from disadvantages, though. As far as restorative dentistry procedures are concerned, the key issue with the standard models consists in the following shortcomings, i.e. no carious lesions replicated, or replicated rather unrealistically, inappropriate hardness of the hard tissue imitation material, and, last but not least, far too perfect, repetitive anatomical characteristics of the teeth themselves [4, 5]. The extracted teeth, on the other hand, pose yet another problem, i.e. actually getting hold of the suitable teeth, let alone an obvious hazard of cross-infection [6–8].

In the subsequent years, the students start pursuing their clinical assignments and carry out various treatment procedures on the patients. Good training, not only in theoretical background, but also in the hands-on approach to their duties, is crucial for ensuring that dental treatment provided by the students still remains in full conformity with professional guidelines. A study by Zarzecka *et al.* indicates that the stress level experienced by dental students transitioning from the pre-clinical to the clinical classes keeps on rising with each passing year of the studies [9]. A quest for new solutions in pre-clinical education by way of having the 3D teeth models introduced, with a view to enhancing the students' hands-on skills, may appreciably contribute to overall reduction of stress, when pursuing a diversity of clinical procedures.

The first 3D tooth model was made back in 1983, by Charles Hull, with the aid of the sterolithography technique [10]. It was not until the 1990s, however, that 3D printers actually found their use in medicine, including dentistry [10, 11]. Reports on the potential to make use of the 3D models in teaching dental students appeared throughout the last decade. They predominantly focused on prosthodontics, and on dental surgery [4, 12–22].

Manifestly fewer papers addressed making use of the 3D teeth models as the teaching aids in restorative dentistry and endodontics [23, 24]. The study aimed at designing and printing out an original 3D model of the mandible, including the teeth, in conjunction with the replication of carious lesions of different classes (according to Black's classification), and of the pulp, as well as aimed to address the following

research questions: How do the students rate the 3D teeth models in comparison to the extracted teeth and the standard models? In which specific procedures in the restorative dentistry can the 3D teeth models be established as the most useful teaching aids, when carrying out any hands-on dental procedures?

Materials and Methods

The 3D teeth models were printed out in full conformity with a Cone Beam Computed Tomography (CBCT) scan of the patient's mandible (Orthopantomograph OP 3D Pro, KaVo, Germany). The DICOM files originating from CBCT were then converted into STL with the aid of Mimics Medical version 21.0 (Materialise, Belgium). At the model design stage, Netfabb Standard 2020 (Autodesk, USA) and 3-Matic Medical 13.0 (Materialise, Belgium) software packages were applied to replicate the caries in the first molars, premolars, and lateral incisors, in line with Black's Class I, II, and III, respectively.

Two technologies were applied to have the respective components of the 3D models printed out, i.e. stereolithography (SLA) (Formlabs FORM2 printer, USA) and Fused Deposition Modeling (FDM) (3DGence Industry F340 printer, Poland). The base for the mandible, ready for being fitted into the Dental Patient Simulator (DPS) was printed using Acrylonitrile Butadiene Styrene (ABS) in the FDM technology, whereas the remaining components were made with the aid of SLA technology. The alveolar part of the mandible, where the teeth were fixed, was made from Elastic Resin, the teeth from Rigid Resin and White Resin and the carious lesions from Black Resin. The pulp was replicated by making use of an impression material.

The cost of printing out a single complete 3D model was about 115,00 EUR, whereas the cost of a single tooth approximated 2,00 EUR.

The study protocol was attended by 22, 5th-year dental students i.e. 17 (77.27%) women and 5 (22.73%) men; mean age 24 years. All participants were volunteers and already had some experience in treating caries, as well as in the root canal treatment (RCT) to their credit. Before the study protocol commenced, the 3D models of the mandible were fitted into the DPS, so as to simulate as realistically as possible the conditions routinely experienced in a clinical setting.

The students' tasks consisted in (1) preparing and filling in a Class II carious lesion in the first molar, (2) preparing and filling in a Class III carious lesion in the lateral incisor, (3) preparing a Class I carious lesion in the first premolar, and in the trepanation of the pulp chamber, in conjunction with an application of a temporary filling to the cavity (Fig. 1a, 1b, 1c). All procedures were carried out after the teeth had been isolated with a rubber-dam.

Following the completion of the treatment procedures, the students were asked to fill in a 3-part questionnaire. The first part addressed the actual number of cavities

Fig. 1a. 3D models of mandibular teeth isolated with a rubber-dam.

Fig. 1b. Partially prepared cavity in the 3D model of the first mandibular molar, well visible carious lesions in the first premolar and lateral incisor.

Fig. 1c. The view following the trepanation of the 3D model of the mandibular first premolar, the pulp is clearly visible.

filled in and the RCTs completed during a clinical course. The second part focused on rating the 3D teeth models in comparison with the extracted teeth and the standard models, as well as on putting down specific recommendations for making use of the 3D teeth models in the pre-clinical training schemes. The students were supposed to respond in line with a 5-point Likert scale. The third part consisted of a series of free text questions on the key advantages and disadvantages of the 3D teeth models as the teaching aids.

The comparison of qualitative variables across respective study groups was completed with the aid of the chi-square test (with Yates correction for 2×2 tables), or Fisher's exact test, where the low anticipated numbers appeared in the tables. The analysis (having assumed a significance level of 0.05) was carried out in R, v. 4.0.5. (R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria).

The study had prior been endorsed by the University's Bioethics Committee (Ref. No. 1072.6120.154.2020).

Results

The students were already experienced in clinical work with the patients. Twenty (90.91%) students had prepared and filled in over 25 carious cavities during their clinical classes to date, the remaining two (9.09%) — appreciably less. Their hands-on experience in the RCT was as follows: 15 (68.18%) students had prepared 1–3 canals, 7 (31.82%) — 4 or more. The actual number of the filled-in root canals was different, i.e. 14 (63.64%) students completed between 1 and 3 root canals, and 8 (36.36%) completed 4 and more.

The students who had prepared fewer root canals rated appreciably higher overall usefulness of the 3D teeth models in acquiring specific manual skills regarding the placement of a rubber-dam ($p < 0.05$).

In the students' opinion, the 3D teeth models proved well capable of replicating adequately both the tissue hardness and the anatomical characteristics of the teeth, whereas the replication of the soft tissue characteristics was rated the weakest component. Replication of carious lesions and the pulp were also rated by most participants as adequately, or perfectly representative of their natural counterparts. A detailed evaluation of the 3D tooth model, in comparison to standard and natural teeth, is addressed in Fig. 2a, 2b.

When asked about overall usefulness of the 3D teeth models in teaching various procedures in restorative dentistry with endodontics, the highest rated components of the training proved the carious treatment, then rubber-dam placement, and the pre-

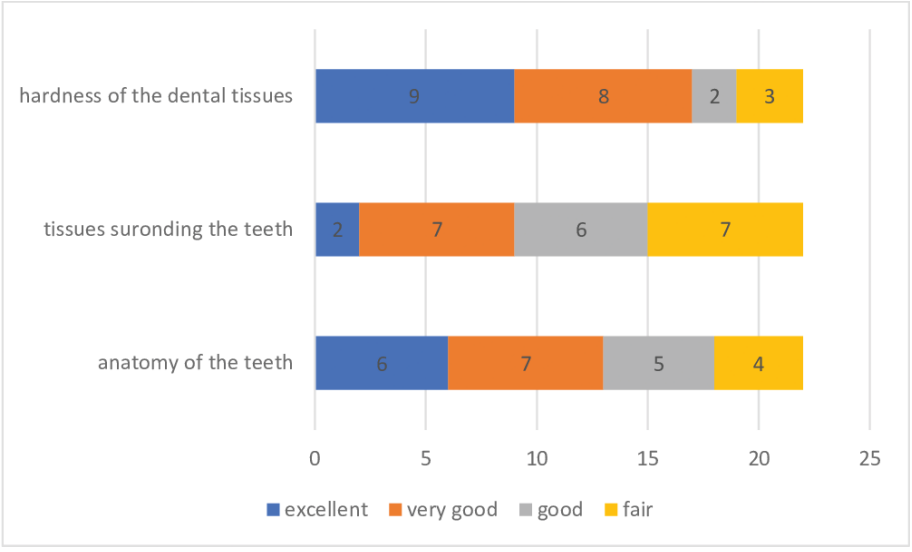

Fig. 2a. Representation of respective structural variability within the 3D model, in comparison with the standard teeth.

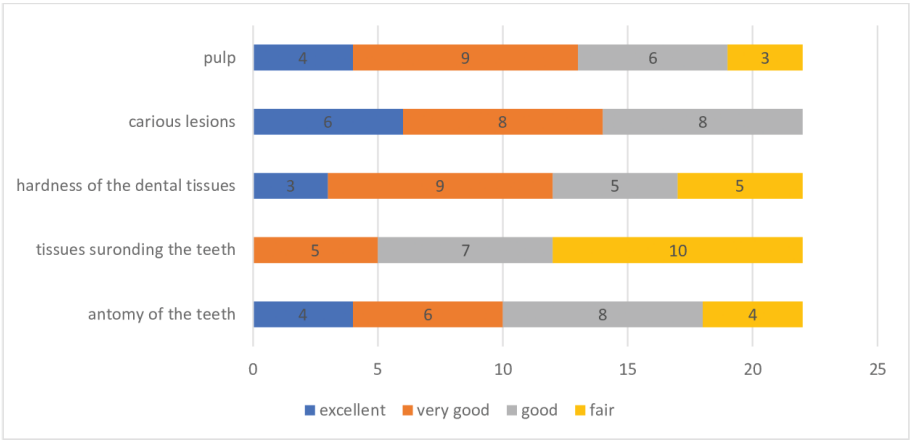

Fig. 2b. Representation of respective structural variability within the 3D model, in comparison with the natural teeth.

paration of endodontic access. On the other hand, the students indicated that the 3D teeth models were not particularly helpful in diagnosing caries (Fig. 3).

Out of all participants, 21 (95.45%) students recommended the introduction of the 3D teeth models into the teaching of conservative dentistry with endodontics at the pre-clinical stage, as well as asserted that working on a 3D model might appreciably aid

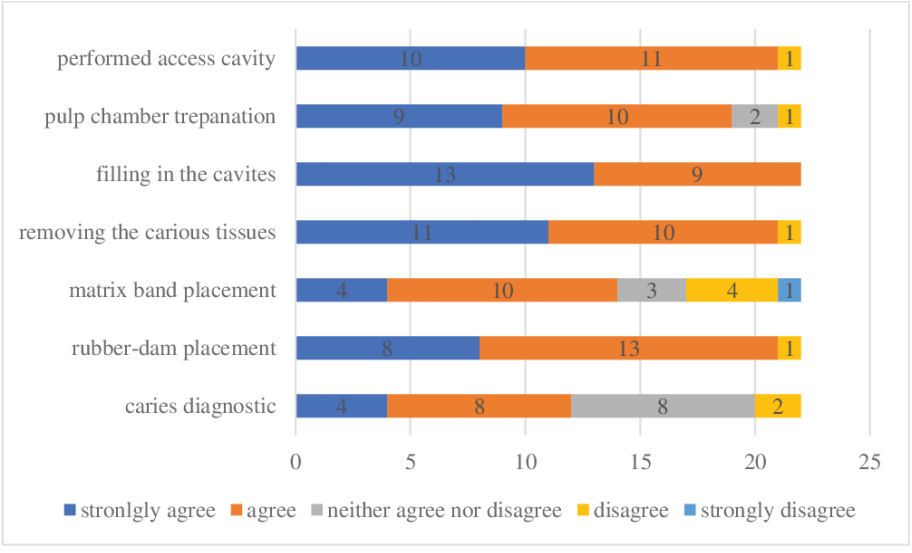

Fig. 3. Assessment of overall usefulness of the 3D teeth models as the teaching aids applied during the hands-on training in respective procedures in restorative dentistry with endodontics.

improving their hands-on skills in cavity preparation and filling in. They also rated the replication of the soft tissue hardness and the anatomical characteristics of the 3D teeth models significantly higher, as compared to the standard ones ($p < 0.05$). The majority of students, i.e. 20 (90.91%) were also positive that working on a 3D model might well contribute to enhancing individual hands-on skills in the trepanation of the pulp chamber. At the same time, they rated the replication of anatomical characteristics in the 3D models significantly higher, as compared to the standard ones ($p < 0.05$).

All the students addressed the free text questions. Among the key advantages offered by the 3D teeth models they specifically highlighted realistic replication of overall anatomical characteristics of the teeth, adequate replication of carious lesions, pulp chambers, and appreciably better imitated tooth tissue hardness, as compared to the one encountered in the standard teeth. The key disadvantages were identified as there being no distinction retained between the enamel and the dentin, as well as poor stabilisation of the teeth in the alveoli.

Discussion

The standard teeth models, or the extracted teeth, are used in the course of the preclinical classes, even though the students argue that the standard models are anatomically far too perfect, and as such simply fail to take due account of natural variability between respective patients' teeth [16, 23]. The original 3D model replicating the mandible, inclusive of the teeth, was made against the characteristics provided by the patient's CBCT, thus facilitating true-to-life anatomical replication, much appreciated by the students.

Besides, the 3D teeth models at issue were also characterised by the replicated crowns, along with the root canals, whereas the pulp was replicated with the aid of an impression material. It was also possible to have the respective teeth repositioned, as they were not permanently fixed in the alveoli. The 3D teeth models were fitted into the DPS, inclusive of the opposite teeth, effectively facilitating work with the patient in a supine position. Working with the 3D models mounted in the DPS avails the students of a better spatial orientation within the oral cavity, as well as enhances overall manual, as well as visual-manual coordination, when carrying out pertinent dental procedures.

The 3D teeth models actually addressed in the published studies were subject to evaluation by dental students, and occasionally also by the dentists. An important factor taken into account was the actual material a particular model had been printed out of, along with its essential characteristics.

There is no uniform terminology agreed among the investigators with regard to a specific criterion for evaluating the materials used for 3D printing. Some authors focus on assessing hardness, others on haptic impressions while grinding, others still on the actual rate of material removal.

In the studies of Hohne *et al.*, overall hardness of the material used for printing out the 3D teeth models was assessed at the tooth preparation stage for the prosthetic crowns to be fitted, and rated as adequate by the students, whereas haptic impressions received a slightly higher rating [16, 17]. In the endodontic model by Reymus *et al.*, overall hardness of the models was compared to the extracted teeth and rated as lower, which affected the ease of preparation work itself [23]. On the other hand, the 3D model created by Marty *et al.* indicated an unrealistic rate of material removal in the students' opinion [5]. In the original 3D tooth model, however, overall hardness of the material used for printing was rated as very high.

Among the disadvantages of the 3D teeth models, as referenced in the published studies, absence of a gingiva mask, or an unrealistic imitation of the soft tissue were highlighted most frequently [4, 5, 18, 19]. Regrettably, also in the original 3D tooth model, adequate imitation of the soft tissue was identified as an issue, prompting numerous critical comments from the students. The resin used for imitating the alveolar part of the mandible proved far too flexible in practice, consequently causing excessive tooth mobility. This obviously calls for further refinements to be implemented at the design stage.

The carious lesions in the 3D teeth models were replicated, whilst making use of different methods. Kröger *et al.* used the so-called support material for this purpose, which was softer than the actual tooth tissue replication material, whereas the students pointed out there was no difference in colour between the caries imitation and the tooth tissue itself [4]. Höhne *et al.* used the self-curing resin, whereas Marty *et al.* simply left the carious cavities hollow [4, 5, 15]. In the original 3D tooth model, the cavities of different classes (in line with Black's classification) were made with the aid of a black resin, so as to make their appearance suitably realistic.

The way the carious lesions were replicated in the original 3D tooth model was appreciated by the students, as most of them believed that working on a 3D model may appreciably enhance their manual skills in cavity preparation and filling in. The students particularly appreciated the presence of a pulp, as a characteristic image of the pulp chamber vault was thus ensured in the deep cavities, owing to pulp proximity, consequently making it easier to assess the depth of the cavity more effectively.

Although the present study is focused predominantly on the treatment of caries, it is well-worth highlighting at this juncture that the 3D teeth models allowed the students to implement the initial stage of RCT by the trepanation of the pulp chamber of a 3D tooth model, which was a true-to-life replica of a natural tooth. The tooth model was fixed in a 3D model of the mandible, duly secured in the DPS, whereas during their pre-clinical practical classes the students often enough have to pursue their work on the stand-alone benchtop endodontic models.

According to the survey of 98 dental students, as conducted by Davey *et al.*, more than half of them did not feel skilled enough to attempt the RCTs on their own. These

results varied slightly, depending on the actual year of the dental studies they were on, and a particular group of the respondents approached with the survey [25]. A study by Baaji *et al.* established that overall self-efficacy in the students carrying out RCTs increased with the number of teeth actually treated, even though with regard to the molars and repeated RCTs, their self-efficacy dropped [26].

It would appear that getting the dental students trained to work with endodontic patients on the 3D teeth models embedded in the DPS might well offer a viable method of teaching in the near future. As overall body of experience gained in clinical work implies, not every patient with a referral for the RCT may be assigned to the students' care, mostly in view of its complex character. On the other hand, the 3D teeth models have clear potential for different types of teeth to be printed out, in due account of their anatomical variabilities. When responding to the free text questions, the students highlighted the clear advantage of moving progressively from the standard models, through the 3D teeth models, right up to the fully-fledged, clinical treatment procedures.

In the majority of the studies under review, the respondents assessing the 3D teeth models highlighted their usefulness in enhancing their hands-on skills for clinical work in various areas. In the opinions of dental surgeons, the 3D teeth surgical models are suitable, or very suitable for surgical education [19]. Likewise in endodontics, the 3D teeth models were rated by the students as highly relevant in clinical terms, and clearly recommended in endodontic education or prosthodontics, as students felt well prepared in a realistic approach to dentin post-preparation [14, 27]. On the other hand, in traumatology, the respondents reported to have gained new insights into this area, and 97% felt far better prepared for treating traumatic dental injuries [28].

The designing and printing stage is where certain limitations in acquiring the 3D teeth models are encountered, though. In order to have a 3D tooth model made, based on a patient's CBCT scan, some IT processing is required, involving not only the conversion of DICOM files into STL, but also the actual modification of the model with the aid of specialised, dedicated software. The printing itself entails making use of highly specialised 3D printers, frequently taking advantage of a diversity of technologies. Consequently, a diversity of services is required from a multi-specialist team which needs to be assembled in the first place, as well as remain on permanent stand-by.

Conclusion

In the course of dental studies, practical classes make up the key component in the hands-on training of prospective dentists. The students were quite appreciative of the 3D teeth models, mostly in view of their adequate replication of basic anatomical characteristics, and good imitation of both the carious lesions, and the pulp chamber.

When asked about overall usefulness of the 3D teeth models in teaching various procedures in restorative dentistry with endodontics, the students enumerated carious treatment, then rubber-dam placement, and finally the preparation of endodontic access as the highest rated components at the hands-on training stage.

The 3D teeth models are believed to be well capable of offering a viable alternative to the standard models and the extracted teeth at the pre-clinical stage of the training, as there is an appreciable potential for different types of teeth to be printed out, in full consideration of their anatomical diversity. They effectively facilitate moving on progressively from the standard models, through the 3D teeth models, all the way up to the fully-fledged, clinical treatment procedures.

More research is still required on the actual methods of printing out such 3D teeth models in terms of incorporating further anatomical refinements, particularly with regard to more true-to-life replication of the soft tissue characteristics.

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Conflict of interest

None declared.

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