BMC medical education

Using a new endodontic tooth model as an alternative in clinical education course during the Covid-19 pandemic

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Running Title: New tooth model and endodontic education

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Abstract

Background The COVID-19 pandemic massively impacts endodontic teaching, and a dramatically reduced number of patients is registered in clinical courses. This could be countered with suitable training aids. Based on treatment errors made by students in the last five years of endodontic courses at RWTH Aachen University (Germany), a new artificial root canal treatment model (DRSK RCT) was developed. The model was aimed to be radiopaque and to simulate the tactile feel during instrumentation in a realistic manner. Unlike already existing 3D-printed tooth replicas, the RCT has anatomical root canals with a narrow lumen with its width matching an ISO size 6 endodontic file.

Methodology 35 fourth-year students and seven dental demonstrators performed endodontic treatments on both the DRSK RCT and extracted teeth. Students and demonstrators answered a questionnaire on a scale ranging from 1 to 7 (poor to high) for different items (part 1). After the first study, changes in the materials and root canal anatomy were applied to the model. Then, the whole study was repeated and evaluated (part 2). Finally, it was evaluated whether the models could replace patient treatment during the Covid-19 pandemic.

Results Ratings by students and dental instructors (5.1 ± 0.4 and 5.3 ± 1.5 [mean ± SD], respectively) in the first study increased after modifications of the DRSK RCT (5.5 ± 0.5 and 6.2 ± 0.8, respectively). Radiographs of the models were excellently assessable. The properties of the DRSK RCT were found to be realistic, thus allowing students to perform a satisfactory simulation of root canal treatment and being rated sufficient in substituting patient treatment during COVID-19 pandemic.

Conclusion The analysis suggests that the DRSK RCT has the ability to improve endodontic technique and education. Visible root canals enable students to observe the treatment process. All steps of a regular root canal treatment can be simulated. Further studies are needed to investigate the outcome of treating the first patient after practicing on the DRSK RCT.

Background

Similar to any other field of knowledge, dentistry constantly embraces novel and innovative modes of training that could potentially facilitate and improve the learning curve for new students. For endodontic education, attempts were made to establish guidelines for the undergraduate training in dental schools [1], which can ensure the achievement of a certain level of competence. To further improve the endodontic education, new forms of teaching methods are required. A study from the United Kingdom showed that teaching methods developed during the last decade led to a wider variation of methods [2]. Despite this, several studies point out that the quality of root canal treatments performed by undergraduate students is often not satisfactory [3, 4, 5, 6, 7, 8]. Thereby, the way of teaching endodontics has a major influence on the quality of root canal treatments performed by students [9].

With regards to endodontics, the traditional preclinical training involved practicing the procedure on extracted natural teeth. Nevertheless, this practice was fraught with concerns over infection control and required disinfection of the teeth [10]. Some materials traditionally used for the purpose of efficient disinfection, such as formalin, proved to have hazardous effects of their own [11]. Furthermore, the supply of natural teeth is not infinite, and combined with the dwindling number of extracted intact teeth - probably as a result of improvement in health standards - it presents a problem for instructors and students in preclinical endodontics [12].

The COVID-19 pandemic emphasizes the importance of alternative teaching methods in dental education and both, students and instructors prefer these methods over having a non-semester [13]. Current protective measures have a massive impact on university teaching [14, 15]. Especially the field of endodontics is affected, since teaching in clinical courses includes patient treatments that cannot be simply substituted by e-learning programs. Although safety concepts may not completely prohibit patient treatments, a very reduced number of patients is evident

due to the pandemic. Effective training models that enable the implementation of a realistic root canal treatment, could adequately meet these challenges.

The simplest of the alternative endodontic training models come in the shape of endodontic blocks with a built-in conduit that approximates in its shape and diameter the root canals of natural teeth [16]. Because they do not represent the external anatomy of the crown and root, these endodontic blocks are of limited educational value. These models do not allow the students to learn how to avoid the procedural problems pertaining to the distance between the canal and external surface of the tooth and lateral or apical perforations of the roots.

Further advances in 3D printing technology promised more sophisticated models simulating a complete tooth including a hollow space representing the root canal system. Apart from their application in pre-clinical courses, these models can be also used in the context of researchers requiring a simulation of the internal anatomy of the teeth [17]. In recent years, different brands of such models have been brought to the market, in turn prompting researchers and academics to perform studies and investigate their properties and suitability as training tools, thus replacing the extracted teeth. Another study found artificial tooth models suitable for endodontic training [18]. Nevertheless, the results of these studies suggest that complete replacement of natural teeth with artificial teeth for endodontic training should be regarded with caution. The physical properties of the models have been of special concern to preclinical endodontics instructors. To be suitable for the desired learning experience, these models are expected to feature physical properties as similar as possible to those of a natural tooth. However, studies showed that, despite advantages of artificial teeth, their physical characteristics are not yet completely satisfactory [19, 20]. In case of one particular model made from a hydroxyapatite-based matrix, a study showed that it is similar to a natural tooth in regard to many physical properties [21]. This study focused exclusively on the physical properties of the model. It did not provide any

information on the actual experience of practicing root canal treatment on synthetic teeth made from this material.

Finally, a recent study introduced the concept of 3D-printed replicas of extracted teeth for endodontic training [22] and recommended it as a practice that dental schools have to embrace. In this study, the researchers produced exact copies of natural teeth and measured their properties and accuracy. However, there remain limitations associated with this concept, and therefore there is a continued demand for commercially produced models. Any modification of the model design, including shape, curvature, length, and width of the canals, falls beyond the scope of the proposed simple reproduction of a micro-computed tomography (micro-CT) file. It can only be achieved by employing computer-aided design software applications, which - owing to their sophistication - normally necessitates enlisting the help of expert personnel with computer design skills.

The present study aimed to evaluate the artificial root canal treatment model (DRSK RCT), which is based on errors made by students in the last 5 years. In contrast to already existing 3D-printed tooth replicas, the DRSK RCT aims to have root canals with a narrow lumen with its width matching an ISO size 6 endodontic file so as to enable students to negotiate the root canal system with endodontic scouting files. We evaluated whether the DRSK RCT is radiographable and also to what extent it permits practicing various shaping and cleaning techniques. In addition to measuring the physical properties of this model, the study aimed to assess the subjective experience of the users (including both students and instructors). By questioning participants about every stage of the root canal treatment performed on this model, the present study evaluated the educational value of DRSK RCT from a practical standpoint. The participating students and dental instructors assessed the DRSK RCT model with regard to its physical properties and its suitability to realistically imitate an endodontic treatment, to optimize the tooth model according to the results of the evaluation for endodontology courses.

Finally, it was evaluated whether the models could replace patient treatment during the Covid-19 pandemic.

Methods

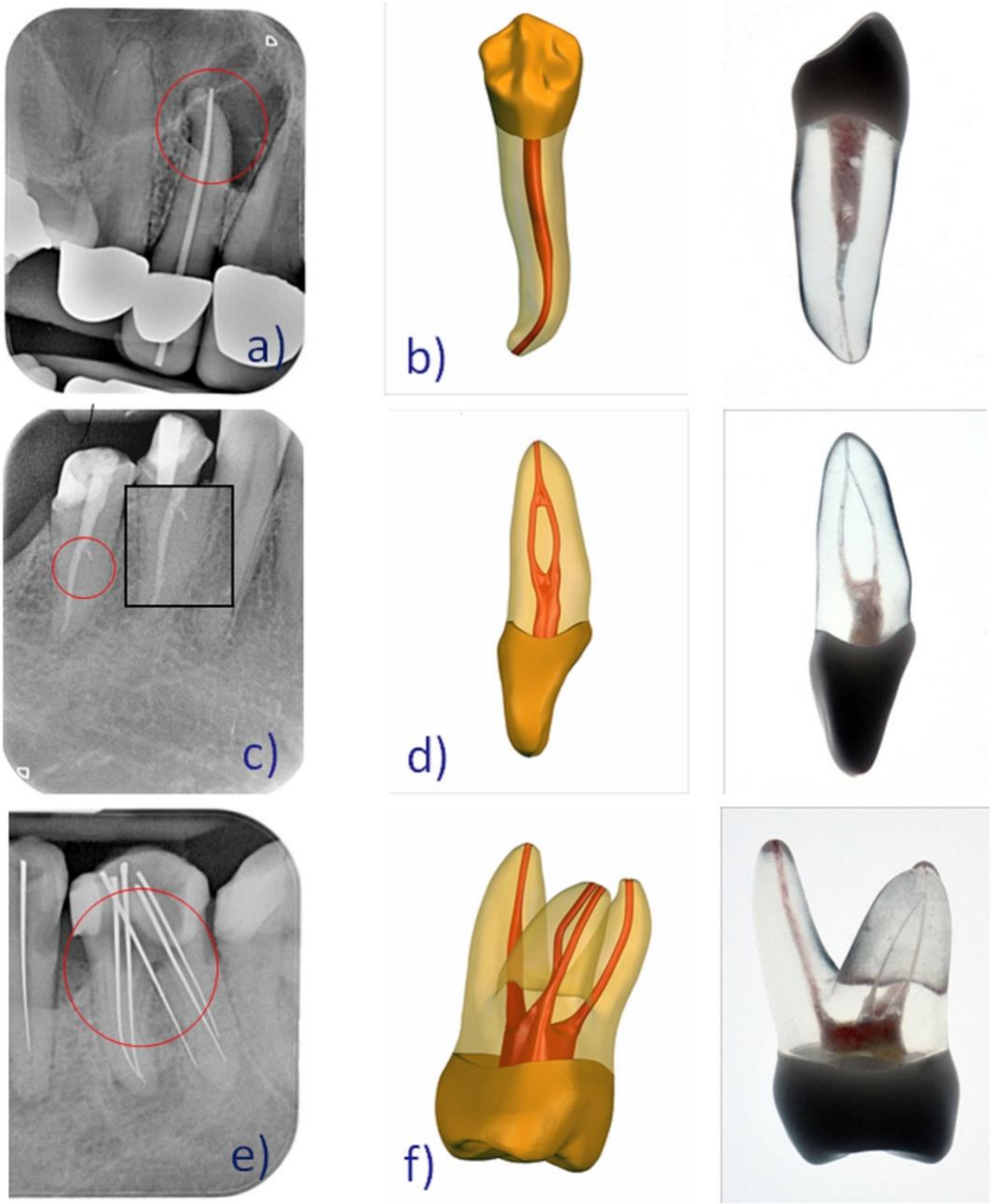
Thirty-five students who had successfully completed the sixth semester - and therefore had knowledge of endodontics - and seven instructors participated in this study. The study was performed in the dental faculty of RWTH Aachen University in Germany, after getting approval of the internal ethics committee.

The Artificial Root Canal Treatment Model (DRSK RCT)

The model is manufactured by DRSK Group AB, Sweden (https://drsk.com/pages/Training/RCT/root_canal_model_RCT.html). It comprises a model designed and prepared in 3D with pulp cavity and root canal(s) that are considerably narrow in dimensions and shape than their natural counterparts. The model is designed for practicing every stage of a root canal treatment. Tooth models contain complete and intact crowns and roots with a hollow space inside, simulating the pulp chamber and root canals. To achieve a more realistic representation, the hollow space in DRSK RCT was filled with a soft red-colored resin imitating the pulp.

The DRSK RCT used in this study was developed based on commonly seen errors made in the last five years by students of endodontic courses in RWTH Aachen University in Germany (Figure 1).

Figure 1



The roots of DRSK RCT were transparent, which permitted the observation of the progression of the simulated treatment (Figure 2).

Figure 2

We developed three variations of tooth models, representing different types of teeth: incisors, premolars, and molars. The incisor was represented by a model of a first maxillary incisor. A hidden second root canal was designed as a special feature of this tooth model. Undetected root canals often lead to failure of endodontic treatment. Inexperienced students often fail to detect all existing root canals of a tooth, especially when the number or configuration of root canals deviates from the norm. As an example of a premolar, a mandibular first premolar with a single root canal was chosen. It has been observed that students tend to straighten root canals during mechanical preparation by not bending the files used. The chosen anatomy of the premolar in the DRSK RCT model makes it inevitable to carefully scout the root canal with a bent file to preserve its anatomy and not be stuck in the apical third of the model root canal without entering the apical constriction.

A maxillary first molar with three roots and four root canals was selected to demonstrate molars. The molar model featured a second mesiobuccal root canal (MB2) corresponding to the

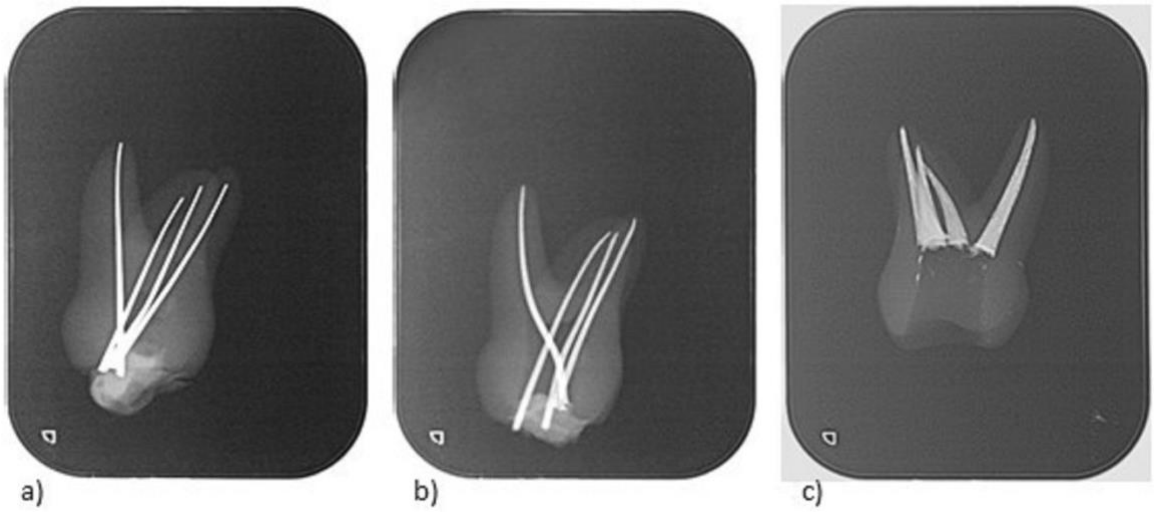
established predominance of this root canal configuration for maxillary first molars [23]. While trying to locate the MB2, students - owing to their lack of experience - may cause perforations in the pulp chamber floor. Unsatisfactory anatomical skills lead to drilling in wrong places to locate the MB2. This tooth model will provide knowledge of the location of MB2 and assist in developing the skills to locate it. The study consisted of two parts, as described below.

Part 1 (students)

Before using DRSK RCT, all students practiced on extracted teeth. Then, the participants were asked to perform a routine root canal procedure on the DRSK RCT models, starting by drilling an access cavity with Endo-Z burs (Dentsply Sirona). A secondary access cavity was prepared using Mueller drills (Komet dental) and Gates-Glidden drills (Komet dental).

After taking the radiograph (Figure 3), hand files (K-Files, SybronEndo) were used for mechanical root canal preparation.

Figure 3



Students enlarged the canals until an ISO 35 file could reach the working length. Students continued shaping the canals, using the step-back technique to flare them to the size of an ISO 60 file. Between instrumentation, canals were rinsed and irrigated with 3% sodium hypochlorite solution, and patency was ensured by using ISO size 10 files. Radiographs were taken during

the process in accordance with the routine protocol (once to determine the working length, then with the master cone, and the last one after obturation). For taking radiographs, the setting of the X-ray machine was changed to levels normally used for children. Canal obturation in this study was performed using gutta-percha (ANTAEOS GuttaPercha Points) with AH26 as the sealer.

Part 1 (instructors)

Another cohort in this study consisted of seven instructors who performed the same procedure of simulated root canal treatment - as described for the student group - on the DRSK RCT model. After the procedure, all participants - students and instructors - received a questionnaire about their experience with the model. The questions were in a Likert-type scale format, and they had to be answered by ranking one aspect of the model from the scale of 1 to 7. The higher values for each question indicated a better simulation of that particular aspect.

Part 2 (modified model)

This part of the study was conducted after evaluating the questionnaires answered by both students and dental instructors. According to the evaluations the following modifications were made in the DRSK RCT on the basis of the findings:

Modifications of DRSK RCT: After modifications, the incisor's special feature was the canal morphology, containing a hidden second root canal corresponding to Vertucci type III canal configuration, with buccal and palatal canals merging together in the apical third. The mandibular first premolar single root canal became a J-shaped turn near the apex. The MB2 of the molar was extended. To increase the contrast between the model and gutta-percha, the composition of the material was modified. Furthermore, to improve the tactile feel of entering the pulp of the endodontic model, the composition of the material was changed. Additionally, root canal diameters were reduced for better representation of natural teeth. After the

modifications were implemented, students performed root canal treatments on the new DRSK RCT. For the second part, the same questionnaire was used. In this manner, the differences in ratings could be analyzed.

Evaluation of students' performances

Finally, the seven dental instructors evaluated these simulated treatments. The success of the students' performance was determined by the correct length and shape of the root canal fillings as well as their homogeneity. The correct length was determined by the obturation ending 0.5 - 1 mm before the radiographic apex. All seven dental instructors blindly evaluated all treated DRSK RCT. Only tooth models with correct length, shape, and homogeneity of the root canal filling were rated as "positive" (Table 1).

Statistical Analysis

The accumulated data for the two sets of questionnaires was entered into an Excel spreadsheet and means and standard deviations for each question were calculated. Paired t-tests were performed to compare the data before and after modifications. The significance of differences was determined at $p < .05$. The software IBM® SPSS® Statistics 22.0 (IBM®, USA) was used for all statistical calculations. Graphics were created with Excel (Microsoft Office Excel 2007®).

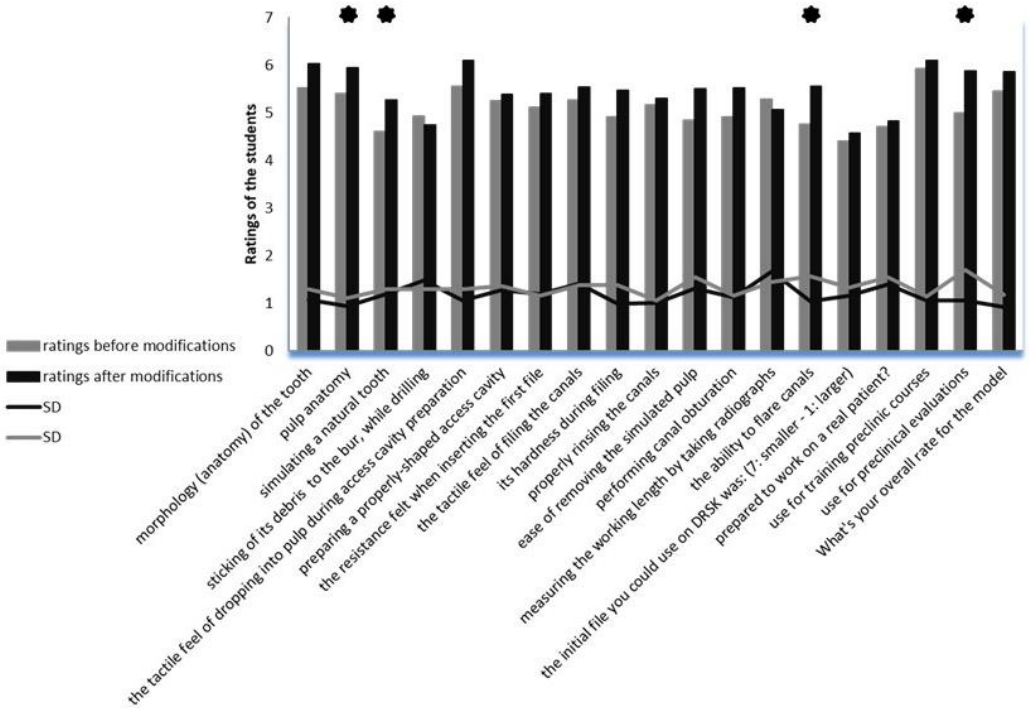
Results

All radiographs of the DRSK RCT were clearly assessable; there was a sufficient contrast between the model and gutta-percha. Moreover, the outlines of roots were completely visible. For the first part of the study, student's ratings of the DRSK RCT ranged from 4.4 to 5.9 on a

scale of 1 to 7, with the mean of their ratings being 5.1 ± 0.4 (mean ± SD). For the second part of the study performed after improving the RCT, students' ratings ranged from 4.6 to 6.1. The mean of their ratings increased to 5.5 ± 0.5 (mean ± SD).

Students' ratings of the pulp anatomy, the ability of the model to simulate a natural tooth, ability to flare canals, and preference for using the DRSK RCT in preclinical evaluations were significantly higher ($p < .05$) for the improved DRSK RCT than for the model used before modifications. The average rating of the pulp anatomy increased from 5.4 ± 1.1 for the first DRSK RCT to 5.9 ± 0.9 for the improved model. Likewise, the rating of the model's ability to simulate natural teeth increased from 4.6 ± 1.3 for the first DRSK RCT to 5.3 ± 1.2 for the modified DRSK RCT. Furthermore, students found that flaring of root canals could be performed in a significantly better manner on the modified DRSK RCT; the ratings increased from 4.8 ± 1.6 to 5.6 ± 1.0 after the material was modified. In the first part, the mean rating of the suitability of DRSK RCT as an evaluation tool in preclinical course was 5.0 ± 1.7, whereas after modifications, it increased to 5.9 ± 1.1 (Figure 4).

273 Figure 4



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275 The mean ratings by dental instructors increased from 5.3 ± 1.5 to 6.2 ± 0.8 following model
276 improvement (Figure 5). The simulated hardness felt during instrumentation, in particular, was
277 rated significantly higher ($p < .05$) after DRSK RCT modifications (from 5.0 ± 0.7 to 6.3 ± 0.4).
278 When asked about the student's readiness to work on a real patient after practicing on RCT, the
279 mean rating was 4.8 ± 2.3, whereas this rating increased to 6.6 ± 0.7 for the enhanced model
280 (Figure 5).

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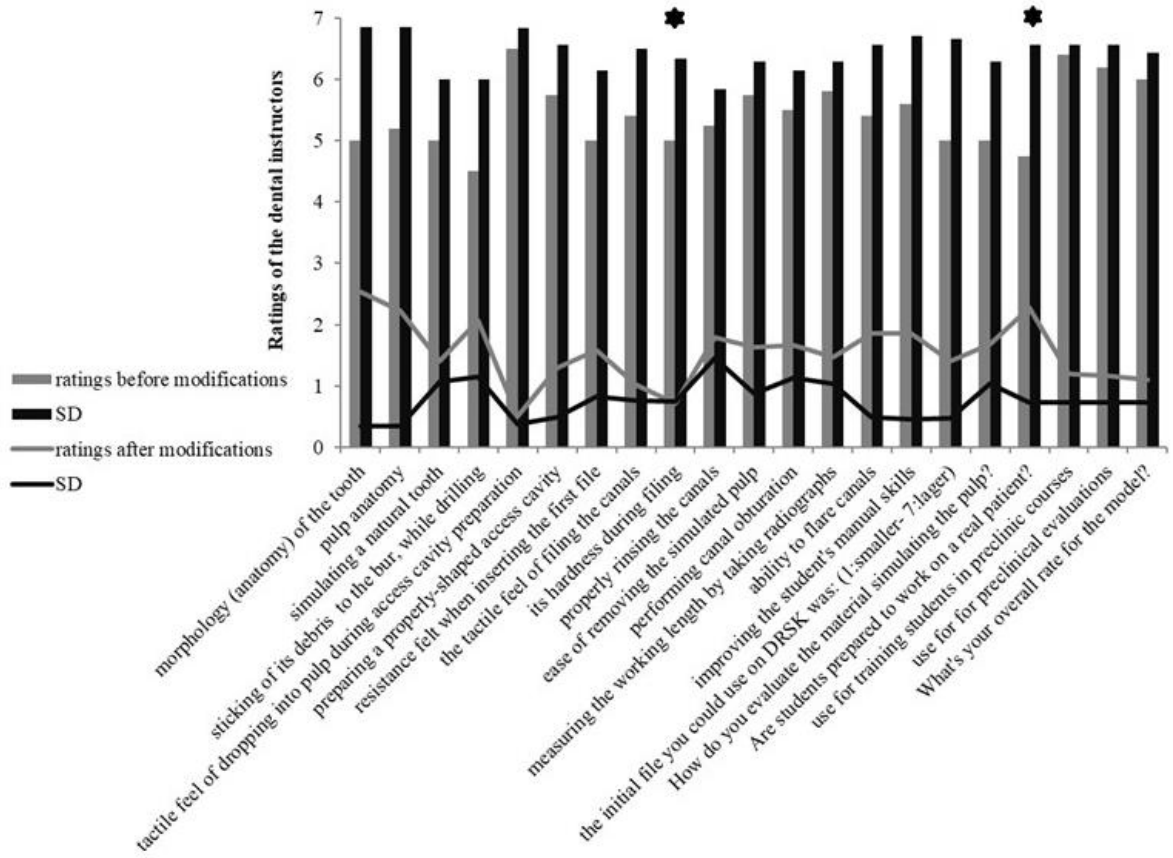
287 Figure 5



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289 In light of the current COVID-19 pandemic, the same seven dental instructors rated the
290 suitability of the DRSK RCT tooth model as a possible substitute for patient treatments at 5.6
291 ± 0.5, in case that root canal treatment is not possible on a patient in the course due to the
292 pandemic.

293 Eventually, the dental instructors positively evaluated 87.35% of the students' performances on
294 the modified training aids, whereas accurate length and homogeneity of the root canal filling
295 were the criteria for a positive rating.

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Table 1 Assessment of root canal treatments performed by students on the DRSK RCT tooth model

Dental Instructor (n = 7)	Students' Success Rate (n = 35)	Successful	Not Successful
Dental Instructor 1	88.57%	31	4
Dental Instructor 2	88.57%	31	4
Dental Instructor 3	85.71%	30	5
Dental Instructor 4	82.86%	29	6
Dental Instructor 5	88.57%	31	4
Dental Instructor 6	88.57%	31	4
Dental Instructor 7	88.57%	31	4

Discussion

In this study, we used an artificial root canal treatment model (DRSK RCT) with an anatomically accurate design. According to its manufacturer, this model can facilitate practicing various shaping and cleaning techniques. Instead of merely measuring the physical properties of this model, the study evaluated the subjective experience of the users (including both students and instructors). The DRSK RCT was designed virtually based on errors made in the last five years by students of endodontic courses. In addition, the anatomy of extracted teeth was used as an overall reference.

When drilling an access cavity, the material used for the tooth model must provide sufficient resistance such that its difference from the material filling the pulp chamber can be perceived clearly. Some authors already mentioned that resin used for endodontic tooth models does not

match the hardness of dentine. Therefore, drilling an access cavity becomes more complicated because the perceived difference in resistance is insufficient [20, 24, 25]. The hardness of dentine-imitating resin and the accuracy of anatomical reproduction affect the degree of difficulty of working with endodontic models in general [26]. Soft resin complicates its distinction from the soft material imitating the pulp, whereas excessively hard resin leads to canal blockage [20].

The DRSK RCT model allows a close simulation of performing endodontic treatment on a natural tooth. This is evidenced by the good ratings achieved in our study. One major alteration to the model involved changing the material used in the manufacturing of DRSK RCT. Consequently, access drilling, root canal preparation, and obturation were performed more easily because the use of harder material offers more resistance. When entering the pulp chamber, the tactile feel is crucial for not harming the pulp floor by accident. This is important for beginners, as they are not used to paying attention to the difference between dentine and the hollow space of the pulp chamber. Sticky debris produced while shaping the root canals blocks the canals and cannot be flushed out easily; however, the stickiness of the debris is reduced when a harder material is used. A material with hardness similar to that of dentine and cement of natural teeth accurately represents the tactile feel while performing root canal treatment on patients, which is the actual reason for using endodontic training aids.

Students highly rated DRSK RCT for potential use in preclinical training, which may be because each model has the exact same anatomy and therefore creates equal and fair conditions for every student. However, there are no two natural teeth with the exact same anatomy. Owing to the large variation observed in the anatomy of natural teeth, a further major alteration made to the studied model included modifying the shapes of the root canals to create a more complex and realistic root canal system. Considering that each tooth requires a unique mode of endodontic intervention, any evaluation procedure based on the use of natural teeth would

become complicated, and questions may be raised over its fairness. These difficulties emphasize the need to seek alternative training models such as the DRSK RCT for practicing root canal treatment during preclinical courses.

The ambition to have models with translucent roots has been on record since as early as 1975 [27]. To that end, different methods have been devised to increase the transparency of the model by applying chemical agents. However, this is often accompanied by undesired effects such as altered physical properties. In the present study, the transparent roots of the model may also have influenced the students' opinion about the DRSK RCT as a training aid in preclinical courses. Because endodontic treatments are performed inside root canals and obscured from view, students often feel insecure when they are unable to see what they are doing. Making the treatment procedure visible allows inexperienced students to gain a deeper understanding of the process. If any error occurs, the cause can thus be quickly identified [21], which is essential for the students' learning process. Such models may also benefit research and testing of certain devices and equipment when it is required to have a direct view of the canals and observe how the equipment functions inside.

In root canal treatments on previous training models, endodontic files of ISO size 15 were used for scouting. Owing to technical considerations, printing tooth models for endodontic training with optimal root canal diameter was challenging [22]. In a study that compared several endodontic training aids, a model named TrueTooth by DELabs, built on the basis of micro-CT scans of natural teeth, was favored owing to its anatomy and material properties being closer to reality [26]. For instance, diameters of the MB2 of TrueTooth #19 (02) are indicated to be 0.12 mm (apical part) and 0.28 mm (coronal part) on its manufacturer's website. Because the initially used file for root canal treatment in real patient is often of a significantly lower ISO size (6, 8, or 10), it is part of our department's protocol of root canal treatment to use c-pilot files of ISO

size 6, 8, or 10 for scouting the root canal system. This needs to be practiced in preclinical training as well and thus requires models with very narrow root canals.

After modification, the DRSK RCT received higher ratings for most points from both cohorts. Owing to the changes in the material, various aspect of simulated root canal treatment such as the stickiness of debris, the feel of drilling the access cavity, or the perceived hardness during filing were improved. Furthermore, radiographs of the tooth model were easier to read as the material became more radiopaque.

The 3D print technology used for producing the DRSK RCT made it possible to change the shapes of the root canals and modify them as desired without incurring substantial costs. The similarity of the DRSK RCT to a natural tooth makes it an ideal training tool in endodontics. The ratings by students and instructors alike point to the suitability of the studied model to be used in endodontic courses. During the COVID-19 pandemic it could be advantageous to incorporate this training aid into the clinical curriculum as supplying students with suitable patients to perform endodontic treatments becomes challenging. Many patients currently avoid the student course out of fear of infection and postpone treatments. In addition, as the number of cases increases, it is becoming more common for patients to be quarantined, making it impossible to carry out treatment properly. As many universities exclusively train students on phantom heads during the current pandemic the tooth model would perfectly fit into their curriculum. Both, students and tutors rated the model as suitable for training and evaluation in preclinical courses and students also felt well prepared for their first root canal treatment on patients. The realistic anatomy and properties of the model allow students to learn the difficulties of endodontic treatments and enable them to practice any clinical step of the procedure. Ratings by the dental instructors indicate its potential use in clinical courses. Reduced patient numbers or concerns about the safety of patients, students and staff in the face of high infection rates might force universities to completely substitute patient treatments with

the work on phantom heads or models [28]. Even though training on models can never replace training on patients, it is probably the best alternative given the current circumstances.

In the last part of the study, seven dental instructors evaluated the results of endodontic treatments performed on the DRSK RCT. The length of the gutta percha filling was taken as the main measure of a successful treatment. The success rate ranged between 82.86% to 88.57%, indicating that the students were able to perform proper endodontic treatments on the developed tooth model. As radiopacity is the key to determine the correct working length, it is crucial that the apical third is clearly visible on radiographs, and thus the correct length of the gutta percha filling can be perceived [26].

A great advantage of using the DRSK RCT is the possibility to modify the root canal morphology as required by tutors. It can be modified to represent certain difficult situations encountered during root canal treatment. By working on the customized DRSK RCT, the students can get equipped to handle difficult cases and learn to manage unfamiliar situations. Further studies are needed to investigate the usefulness of the DRSK RCT by evaluating the outcome of treating the first patient after practicing on the DRSK RCT and comparing the results with those for a control group without prior experience of working on the DRSK RCT.

Conclusion

The DRSK RCT can be used as an alternative to the old-school extracted teeth or as an additional tool for improving dental education. Specifically, the good contrast on radiographs and the realistic and freely modifiable anatomy of root canals makes the DRSK RCT a desirable teaching aid. Furthermore, during COVID-19 pandemic these tooth models could help to ensure teaching endodontics when patient treatment is not possible.

Abbreviations

COVID-19 pandemic: coronavirus disease pandemic

DRSK RCT: name of the tooth model presented in this study

MB2: second mesiobuccal root canal

Declarations

Ethics approval and consent to participate

Ethics approval and consent to participate: The study was performed in the dental faculty of RWTH Aachen University in Germany, after getting approval of the internal ethics committee. The study was conducted in accordance with the ethical standards established in the 1964 Declaration of Helsinki and its subsequent amendments. All participants voluntarily took part in this study and written informed consent was obtained from each participant. The participating students had at all time the opportunity to withdraw their approval without mentioning any reasons.

Consent for publication

Not applicable.

Availability of data and materials

All data are available from the corresponding author on reasonable request.

Competing interests

The authors declare that there were no competing interests.

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None.

Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by SYM and CF. The first draft of the manuscript was written by SYM. All authors (SYM, CF, AH) edited and commented on previous versions of the manuscript. All authors (SYM, CF, AH) read and approved the final manuscript.

References

1. De Moor R, Hulsmann M, Kirkevang LL, Tanalp J, Whitworth J. Undergraduate curriculum guidelines for endodontology. International Endodontic Journal 2013;46(12):1105-1114.
2. Al Raisi H, Dummer PMH, Vianna ME. How is Endodontics taught? A survey to evaluate undergraduate endodontic teaching in dental schools within the United Kingdom. International Endodontic Journal 2019;52(7):1077-1085.
3. Al-Anesi MS, AlKhawlani MM, Alkheraif AA, Al-Basmi AA, Alhajj MN. An audit of root canal filling quality performed by undergraduate pre-clinical dental students, Yemen. BMC Med Educ 2019;19(1):350.
4. Ribeiro DM, Reus JC, Felippe WT, Pacheco-Pereira C, Dutra KL, Santos JN, Porporatti AL, De Luca Canto G. Technical quality of root canal treatment performed by undergraduate students using hand instrumentation: a meta-analysis. International Endodontic Journal 2018;51(3):269-283.
5. Fong W, Heidarifar O, Killough S, Lappin MJ, El Karim IA. An audit on technical quality of root fillings performed by undergraduate students. International Endodontic Journal 2018;51 Suppl 3:e197-e203.
6. Fong W, Heidarifar O, Killough S, Lappin MJ, El Karim IA. An audit on technical quality of root fillings performed by undergraduate students. Int Endod J 2018;51 Suppl 3:e197-e203.
7. Polyzos NK, Sarris KG, Pita AI, Mikrogeorgis GV, Lyroudia KM. Quality of Root Canal Fillings Performed by Undergraduate Students and the Related Factors on the Treatment Outcome: A 2- to 5-Year Follow-Up. Eur Endod J 2018;3(3):179-185.
8. Saatchi M, Mohammadi G, Vali Sichani A, Moshkforoush S. Technical Quality of Root Canal Treatment Performed by Undergraduate Clinical Students of Isfahan Dental School. Iran Endod J 2018;13(1):88-93.
9. Baaij A, Ozok AR. Method of teaching undergraduate students to perform root canal treatment: It's influence on the quality of root fillings. Eur J Dent Educ 2018;22(2):e221-e227.
10. Dominici JT, Eleazer PD, Clark SJ, Staat RH, Scheetz JP. Disinfection/sterilization of extracted teeth for dental student use. Journal of Dental Education 2001;65(11):1278-1280.
11. Hope CK, Griffiths DA, Prior DM. Finding an alternative to formalin for sterilization of extracted teeth for teaching purposes. Journal of Dental Education 2013;77(1):68-71.
12. Qualtrough AJ. Undergraduate endodontic education: what are the challenges? British Dental Journal 2014;216(6):361-364.
13. Schlenz MA, Schmidt A, Wostmann B, Kramer N, Schulz-Weidner N. Students' and lecturers' perspective on the implementation of online learning in dental education due to SARS-CoV-2 (COVID-19): a cross-sectional study. BMC Med Educ 2020;20(1):354.
14. Haroon Z, Azad AA, Sharif M, Aslam A, Arshad K, Rafiq S. COVID-19 Era: Challenges and Solutions in Dental Education. J Coll Physicians Surg Pak 2020;30(10):129-131.
15. Lieberman JA, Nester T, Emrich B, Staley EM, Bourassa LA, Tsang HC. Coping With COVID-19. Am J Clin Pathol 2020.
16. Spenst A, Kahn H. The use of a plastic block for teaching root canal instrumentation and obturation. Journal of Endodontics 1979;5(9):282-284.

17. Boutsioukis C, Verhaagen B, Walmsley AD, Versluis M, van der Sluis LW. Measurement and visualization of file-to-wall contact during ultrasonically activated irrigation in simulated canals. International Endodontic Journal 2013;46(11):1046-1055.
18. Bitter K, Gruner D, Wolf O, Schwendicke F. Artificial Versus Natural Teeth for Preclinical Endodontic Training: A Randomized Controlled Trial. Journal Endodontics 2016;42(8):1212-1217.
19. Al-Sudani DI, Basudan SO. Students' perceptions of pre-clinical endodontic training with artificial teeth compared to extracted human teeth. European Journal of Dental Education 2017;21(4):e72-e75.
20. dos S. Luz D, de S. Ourique F, Scarparo RK, Vier-Pelisser FV, Morgental RD, Waltrick SB, de Figueiredo JA. Preparation time and perceptions of Brazilian specialists and dental students regarding simulated root canals for endodontic teaching: a preliminary study. Journal of Dental Education 2015;79(1):56-63.
21. Robberecht L, Chai F, Dehurtevent M, Marchandise P, Becavin T, Hornez JC, Deveaux E. A novel anatomical ceramic root canal simulator for endodontic training. European Journal of Dental Education 2017;21(4):e1-e6.
22. Reymus M, Fotiadou C, Kessler A, Heck K, Hickel R, Diegritz C. 3D printed replicas for endodontic education. International Endodontic Journal 2019;52(1):123-130.
23. Martins JNR, Marques D, Silva E, Carames J, Mata A, Versiani MA. Second mesiobuccal root canal in maxillary molars-A systematic review and meta-analysis of prevalence studies using cone beam computed tomography. Archives of Oral Biology 2019:104589.
24. Nassri MR, Carlik J, da Silva CR, Okagawa RE, Lin S. Critical analysis of artificial teeth for endodontic teaching. Journal of Applied Oral Science 2008;16(1):43-49.
25. Tchorz JP, Ganter PA, Woelber JP, Stampf S, Hellwig E, Altenburger MJ. Evaluation of an improved endodontic teaching model: do preclinical exercises have an influence on the technical quality of root canal treatments? International Endodontic Journal 2014;47(5):410-415.
26. Gancedo-Caravia L, Bascones J, Garcia-Barbero E, Arias A. Suitability of different tooth replicas for endodontic training: perceptions and detection of common errors in the performance of postgraduate students. International Endodontic Journal 2019.
27. Hasselgren G, Tronstad L. The use of transparent teeth in the teaching of preclinical endodontics. Journal Endodontics 1975;1(8):278-280.
28. Iyer P, Aziz K, Ojcius DM. Impact of COVID-19 on dental education in the United States. J Dent Educ 2020;84(6):718-722.

Figure Legends

Figure 1. Radiographs showing treatment errors done in student courses (a, c, e). Graphics of the endodontic tooth models that were developed according to the recorded errors (b, d, f).

a) Tooth 12 with j-shape root canal and a via falsa; b) Premolar tooth model with an apically strongly curved root canal (draft + produced model); c) Tooth 45 with a Type II shaped root canal and an incomplete obturated root canal; d) Incisor tooth model with a Type II shaped root canal (draft + produced model); e) Tooth 36 with a perforation of the pulp ground that was assumed to be a further root canal by students; f) Molar tooth model with a hidden mb2 (draft + produced model).

Figure 2. Picture of a DRSK RCT model of a maxillary first molar with completed root filling with gutta-percha points performed by a student with lateral condensation technique.

Figure 3. Radiographs of a maxillary first molar DRSK RCT tooth model: a) lengths measuring with silverpoints b) control of gutta-percha master cones c) control of the completed root canal filling

Figure 4. Bar chart showing the mean opinions of students on helpfulness of tooth model in the first investigation (grey) and the second one after modification (black).

Line: standard deviation/ asterisk: $p < 0.05$

548 **Figure 5.** Bar chart showing the mean opinions of dental instructors on helpfulness of tooth
549 model in the first investigation (grey) and the second one after modification (black).

550 Line: standard deviation/ asterisk: $p < 0.05$