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Title Page

Title: Pilot study assessing 3D-printed teeth as a caries removal teaching tool

Running title: Novel undergraduate caries removal teaching method

Authors:

Ambika Sinha, Dental Core Trainee, Special Care Dentistry, Royal London Hospital, Barts Health NHS Trust, UK.

Cecilie Osnes, Research Assistant, School of Dentistry, University of Leeds, Leeds, LS2 9LU, UK.

Andrew J Keeling, Clinical Associate Professor in Restorative Dentistry, School of Dentistry, University of Leeds, Leeds, LS2 9LU, UK.

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Corresponding first author's current address:

Ambika Sinha, Special Care Dentistry, Royal London Hospital, Barts Health NHS Trust, UK.

ambikasinha@icloud.com

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DR. AMBIKA SINHA (Orcid ID : 0000-0001-5885-7099)
MISS CECILIE OSNES (Orcid ID : 0000-0003-4652-3854)

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Pilot study assessing 3D-printed teeth as a caries removal teaching tool

Abstract:

Introduction: In UK universities, caries removal teaching utilises plastic teeth. This format does not enable students to learn how to distinguish between tooth layers and caries via tactile feedback. The aim of this study was to the assess the applicability of a novel, 3D-printed carious tooth within caries removal teaching.

Materials and methods: Single-material 3D-printed teeth containing simulated tactile caries were developed and 14 final-year undergraduates were briefed to remove caries and minimise damage to healthy tissue within the tooth. Students completed evaluation questionnaires for their opinion of 3D-printed teeth in comparison to plastic teeth and perceived confidence to subsequently treat patients. Cavity preparation perimeters were measured, using photographs with a standard protocol. Heat map analysis illustrated variation in location and extent of cavity preparations produced by the cohort.

Results: Student feedback indicated the 3D-printed caries exercise was positively received, 71.4% agreed 3D-printed teeth would have better prepared students for patient treatment. 78.6% rated their pre-clinical stress/anxiety as 'Very High' or 'High' and 57.1% agreed that if pre-clinical teaching incorporated 3D-printed teeth, their

stress/anxiety when treating their first caries patient would have been reduced. The average perimeter of cavity preparation indicated relative variation, with a maximum perimeter of 19.6mm and a minimum of 10.7mm, and a range of 8.9mm.

Discussion: Introducing 3D-printed teeth into preclinical teaching would allow students to gain confidence in clinically relevant experience in tactile aspects of caries treatment earlier in their training than currently possible.

Conclusion: This study demonstrates student acceptance of an alternative caries removal teaching method, with potential to increase aptitude in caries removal in a clinically relevant manner.

There is no funding to report for this submission, no conflict of interest declared by any authors, this manuscript has not been submitted previously. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Introduction:

Dental caries is the most prevalent preventable disease amongst humans[1]. Demineralisation can extend from the enamel layer of the tooth to the dentine layer; the clinician must be able to distinguish between infected and healthy tooth tissue, despite lack of clearly defined markers[2]. This clinical judgement largely relies upon tactile sensation of tissue consistency[3].

The ubiquitous plastic tooth model is the traditional teaching method for pre-clinical caries removal within the undergraduate dental curriculum, despite its limitations[4]. These artificial teeth do not represent a true carious lesion, due to the lack of any pathology and tactile variability within the models. During clinical caries removal, it is role of the clinician to 'chase' the diseased tissue through the patient's tooth, and judge when sufficient carious tissue has been removed, with particular importance being assigned to caries removal at the amelo-dentinal junction[5], but this anatomical feature does not exist in plastic models[6]. In the pre-clinical teaching lab, students are therefore tasked to produce cavity preparations to specific dimensions, set as assessed tasks during the pre-clinical training. There is no opportunity to distinguish variation between healthy enamel and dentine layers and carious tissue via traditional plastic training teeth, therefore limiting students' understanding of the sensory variations present within real caries removal. As such, a large portion of the skills needed during caries removal is absent from the traditional pre-clinical teaching environment, including the tactile feel of demineralised and carious tissue. An additional limitation of plastic teeth lies in their cost, curbing students' practicing opportunities due to a limited number of teeth allocated per student.

Alternative caries simulation methods include virtual reality simulators, providing haptic feedback[7,8] which may include a virtual mirror and simulated task to complete[9]. However, despite introducing the sensation of varying tooth tissue, this is a step further away from the daily reality of a clinical caries scenario, and a costly option many teaching clinicians are reluctant to embrace. Issues regarding realism and the high cost of equipment make virtual simulation limited to use as only adjunctive teaching modalities, rather than mainstream options[10].

Extracted human teeth are an alternative teaching modality which enables students to put theory into practice in the most realistic clinical setting feasible within the laboratory. Sterilisation of teeth must be in line with infection control guidelines, to inhibit cross-contamination of blood or saliva contact[13]. Due to the structure of natural teeth, acceptable sterilisation can be very difficult or may alter the teeth. Additionally, they may be damaged or infected with blood-borne viruses and contamination risk is heightened in the absence of a liquid coolant in the laboratory[13]. A study highlighted 42% of one dental class tested Tubercullin positive,

as a result of assessments performed on extracted teeth during their university training[14]. Furthermore, access to good quality teeth, with uniform and realistic amounts of caries, is almost impossible. Standardised teaching and assessment are therefore very hard to implement using extracted teeth.

The lack of a uniform method for teaching pre-clinical caries removal was recently highlighted in a survey of dental students' understanding of caries removal. Here, 21 of the 36 U.S. dental schools included teaching relying upon plastic teeth. The survey highlighted inconsistencies in U.S. teaching of caries removal and students' comprehension of assessment of disease stages (i.e. infected vs affected dentine), management and employment of evidence based dentistry. The research indicated that lack of teaching tools to refine students' ability in differentiating carious tissue, was a factor in the irregularities[11].

A qualitative study of dental students' perception of their dental school's teaching methods, indicated that students appreciate timely and constructive feedback on cavity preparations to ensure future improvement and satisfaction[12]. Feedback was reported by some students to be ineffective and brief, a factor which is present when relying solely on tutor assessment of plastic teeth preparation. Additionally, even when accurate and useful feedback is provided, plastic teeth are not a realistic representation of caries and do not facilitate the best possible preparation for students prior to treating real teeth in patients.

Evolution from the conventional caries removal teaching methods is necessary, to expand students' insight into true-to-life caries removal. Additionally, in the current and post-COVID-19 era, it is likely that the use of simulation in dental training will become ever more important, as an adjunct to clinical experience, due to limitations in performance of aerosol generating procedures on patients. Therefore, the pursuit of more clinically realistic and relevant simulation exercises is an important area of research.

The application of the increased anatomical accuracy of 3D-printed teeth has been demonstrated in many aspects of dental training. One study employed 3D-printed teeth for senior undergraduates to practice dentine post placement, a very risky and

complex treatment, which until now students have been unable to practice on a realistic tooth simulation[15]. This research highlighted the scope that 3D-printed teeth can provide in addressing clinical management of complications, in a pre-clinical teaching environment. Additionally, utilisation of 3D-printed teeth in tooth morphology training[16], veneer preparation, dentine bonding practice, insufficient crown management[17] and pre-clinical prosthodontics teaching[18], has been well documented.

While plastic teeth containing simulated caries are commercially available, these are often prohibitively expensive, and tend to rely on coloured lesions, rather than simulating the tactile sensation of drilling caries. The aforementioned 2019 study presented a novel method of 3D-printing carious teeth which simulated the tactile feel of caries by injecting temporary crown resin was into the cavity after printing[15]. The general student consensus was positive, though notably, a lack of consistency of the caries within the teeth was highlighted as problematic. To overcome such issues, a novel method for 3D-printing training teeth containing simulated caries has been developed. Unlike the plastic teeth commonly used for preclinical teaching, these novel teeth include printed lesions which simulate the tactile behaviour of caries. The printed teeth designed for the present study were designed to include the carious lesion (as opposed to printing a void requiring filling post-print), resulting in little or no inconsistencies, and no necessary manual modification of the printed teeth, beyond the standard print processing protocol.

In this paper, we present a novel, cost-effective 3D-printed tooth (upper right first molar, UR6), containing simulated caries alongside a pilot study into student's perception of the training tooth.

Materials and Methods:

The study was conducted within the Leeds Dental Institute Clinical Skills Laboratory, UK. The total number of final year students at the time of this study was 75 undergraduates. All students were eligible and invited to participate in the study via an administrative email advertisement announcing the study's aims and objectives

and requirements from participants. Participant information leaflets and consent forms were distributed and obtained from the students who expressed an interest to take part. Inclusion criteria required all participants to have completed Clinical Skills taught programmes on the curriculum and have had individual experience of caries removal on at least one patient. The exclusion criteria were students within any postgraduate training schemes and tutors, to ensure participants were all at a comparable level of clinical teaching and experience.

Fourteen final year dental undergraduate students from the University of Leeds volunteered to take part in this study (18.6% response rate), all of whom were included within this research.

DREC ethical approval was awarded (approved by the School of Dentistry research ethics committee at the University of Leeds DREC ref: 'FYP20183Dteeth', prior to both quantitative and qualitative data collection.

A 3D-printed upper right first molar containing simulated tactile caries was developed (Fig 1.). The molar teeth were 3D-printed using dental model resin and a Form 3 printer (Formlabs, MA, USA). The carious lesion consisted of a lower density area within the print. Light curing the print object, as is standard protocol for this printer, results in a harder outer layer, giving the impression of enamel, while the inner solid aspects remain slightly softer, like dentine. The tooth was a single material, and uniformly coloured. An artificial radiographic image was programmatically produced by rendering the virtual tooth file in ImageJ[19].

One tooth was distributed to each participant. Participants were provided with a radiographic image of the carious radiolucency within the 3D-printed tooth, to guide the cavity preparation that should be completed within the study (Fig 2.). The students were instructed to utilise the standard conservative instruments available, including high and slow speed burs, to remove the simulated caries to the best of their ability within a 30-minute period. Once the students had considered the caries task completed, they were asked to complete a questionnaire (Fig 3). This provided the student evaluation data. Questionnaire data was analysed to determine student

opinion on 3D-printed teeth as a tactile caries removal teaching modality, and whether they preferred this to the traditional teaching with plastic teeth models.

Occlusal clinical photographs of the cavity preparations were taken from a standardised viewpoint to map surface area and perimeter of the cavity preps, to quantify and assess student performance and examine the variation in student performance. These images were analysed using the Photoshop 'magnetic lasso' tool: the occlusal cavity preparations were outlined and the average surface area and perimeter of each preparation was measured in pixels (Fig 4), by two validators, initially, five times each with an overall of ten times to improve intra- and inter-investigator repeatability. Thereafter each prep was outlined a total of three times and verified by the two examiners simultaneously, with the acceptance criteria that results recorded must fall within 1% of each other. This method achieved an average surface area and perimeter measurement for each students' cavity prep which was then converted to millimetres to produce a clinically applicable and standardised measurement.

Descriptive statistical analysis was then performed using the IBM SPSS Statistics 25 program.

Heat mapping analysis was also employed by overlaying each flood filled outline surface area of the occlusal cavity preparation (Fig 5. and 6.).

Results:

Fourteen participants were voluntarily recruited to this study; there was no power calculation.

Student evaluation feedback:

Analysis of student questionnaire feedback (Fig 3.) highlighted that only 50% of participants selected 'Agree', when asked if they felt fully prepared and clinically ready when treating their first carious lesion in a patient. Whereas, 14.3% stated

'Neither' and 35.7% 'Disagree' or 'Strongly Disagree' for confidence prior to clinical treatment (Table 1.).

64.3% of students stated 'Agree' or 'Strongly Agree' that the 3D-printed teeth were a good simulation of tactile clinical caries removal. In comparison to 28.6% stating 'Neither' and 7.1% disagreeing (Table 1.).

71.4% of student volunteers selected either 'Agree' or 'Strongly Agree' that the 3D-printed teeth would have better prepared them in caries removal, compared to practicing on traditional plastic teeth, as a pre-clinical teaching method. Conversely, 21.4% stated 'Neither' and 14.3% opted for 'Disagree'.

78.6% of students indicated their anxiety and or stress levels to be 'Very High' or 'High' when treating their first clinical caries patient, in comparison to only 21.4% grading their pre-clinical stress/anxiety as 'Low' or 'Very Low', and none of the students experiencing 'Zero' stress or anxiety.

57.1% of students Agreed or Strongly Agreed that prior clinical teaching having employed the 3D-printed teeth could have reduced students' stress and/or anxiety when treating their first caries patient, compared to 28.6% and 14.3% of responses stating 'Neither' and 'Disagree' respectively.

Table 1. Student evaluation questionnaire data

	Strongly Agree	Agree	Neither	Disagree	Strongly Disagree
I felt fully prepared and clinically ready when treating my first carious lesion on clinic:	0	7	2	3	2
The 3D-printed carious teeth were a good simulation of tactile clinical caries removal:	4	5	4	1	0
The 3D-printed teeth would have better prepared me with respect to the clinical procedure, caries removal, compared to the standard plastic teeth training in labs:	5	5	3	2	0
Clinical lab teaching using the 3D-printed teeth would have reduced my stress and/or anxiety when treating my first caries patient:	3	5	4	2	0
	Very High	High	Low	Very Low	Zero
When I treated my first caries patient, my anxiety and stress levels were:	6	5	2	1	0

Caries preparation outcome:

Figure 7. depicts the average surface area and perimeter measurements of the cavity preparations. The highest average perimeter amongst the participants was 19.6mm and the lowest 10.7mm, yielding a range of 8.9mm. For surface area, the highest average amongst students was 22.4mm^2 and the lowest 8.9mm^2, yielding a range of 13.5mm^2. All data for both perimeter and surface area, fall within two standard deviations from the mean result and therefore the results within this sample population are normally distributed with no outliers.

Discussion:

This study investigated the validity and student perception of a novel 3D-printed tooth containing simulated caries with which to teach caries removal in the preclinical skills classroom. Restorative dentistry aims to reinstate the function and structural integrity of carious teeth and embodies a large proportion of treatment delivered by general dental practitioners. Therefore, cavity preparation skill acquisition and development is a fundamental aspect of dental undergraduate training[12]. Dentists must establish how much tissue is acceptable to remove in order to prevent disease progression, whilst conserving tooth tissue, preventing exposure of healthy pulp and increasing tooth longevity, via a minimally invasive technique. Teaching these skills in a simulated environment is a challenge. *The validity* of the current study was investigated by assessing whether all participants were in general agreement over the location and extent of the simulated lesion.

The student evaluation findings of this study indicate relatively positive responses overall, with 64.3% in agreement that 3D-printed teeth provide a suitable simulation of tactile caries removal and 71.4% stating this would have better prepared them for clinical treatment. Additionally, 57.1% indicated this could have reduced their stress during their first experience of caries removal (Fig 3.). This bears relevance to the teaching curriculum, as treating patients as a novice student can be anxiety-

inducing. Hence, teaching tools which could contribute to students' clinical development and confidence, are valuable.

The heat map analysis (Fig 5. & 6.) highlights the variability of students' cavity positioning, straying into different regions of the tooth. This brings to question whether the tooth under investigation contained simulated caries which was too subtle for the participants to be able to identify area where the "carious tissue" ended and "healthy tissue" began, or whether some of the participants were more aggressive than necessary out of a lack of understanding of the task or potentially limited skillset in this area from previous plastic tooth training. Future work investigating whether feedback and further tutorials would result in less wildly deviating preparations by a cohort would be valuable, but was beyond the scope of this study. Furthermore, repeating the operative aspect of the study with an experienced cohort of dentists might help to investigate the construct validity of the 3D-printed carious tooth. The difference between caries removal in experienced dentists vs dental undergraduates has previously been highlighted using haptic simulation[7].

In addition, having a measure with which to assess the students' performance in removing the carious tissue while preserving the healthy tissue would have been valuable. Knowing the true extent of the lesion within the printed tooth is a challenge, as it is a fact that the digital file sent to the printer does not necessarily perfectly match the final tooth produced. Part of the issue here is that the print needs to be light cured – any variation in curing time/intensity may affect the size of the lesion and result in it no longer *quite* matching the CAD file. What we do know, is that all the students were drilling identical teeth; what we do not know is exactly where the lesions ended and healthy tissue started. One solution to this problem would have been to ask a, or a number, of experienced clinicians to do the exact same task as the students and compare the results, using the clinician's preparation as a "gold standard". This would have given a valuable insight into student performance, but was, unfortunately, not carried out during the experiment presented due to time limitations.

Although measurement of the preparation outlines was validated by two investigators, to improve repeatability and reduce stochastic noise measurement error, this is still a crude measure of a two-dimensional image representing a three-dimensional structure. An objective cavity outline measurement was achieved in this study, however volumetric analysis was not feasible within the scope of this study. This could involve placing the cavity prepared 3D-printed teeth in a test tube containing a standardised volume of fluid and assessment of volumetric change to quantify amount of caries removed. Alternatively, a standard camera view, on the visualizer in a clinical skills teaching laboratory, could facilitate an overlay of the ideal cavity outline and aid in assessment and feedback to students.

Additionally, future research could analyse depth measurements of the cavity preparations via cross sectioning the 3D-printed teeth and measuring the true surface area of the cavity to the base. Alternatively, the cavity preparation could be 3D-scanned. These methods would provide a quantifiable, standardised feedback mechanism for students' to be assessed by, supplementing tutor feedback. This could reduce contact time needed between each student and clinical tutors, allowing teaching staff to focus on students who require greater support.

An important aspect of caries removal is ensuring adequate cleaning of the ADJ. An artefact of the printing method does in fact produce a tactile difference in materials between the outer shell and internal solid part of the tooth. As the tooth is uniformly coloured, this area is not visible to the operator, except through careful tactile testing. The aim of this study was to investigate whether the printed teeth were found to be beneficial by the students. The 3D-printing solution is a simple alternative to using solid plastic teeth which may hold the benefit of being able to introduce concepts required for correct clinical caries removal. Future developments in both manufacturing methods and assessment techniques may aid in allowing us to assess the more finessed aspects of caries removal, such as the thoroughness with which the student has cleared the caries at the ADJ, but this is currently not available.

Introducing the 3D-printed teeth presented herein into preclinical skills teaching would allow students to gain clinically relevant experience, and confidence, in the

tactile aspects of caries treatment, earlier in their undergraduate training than what is currently possible. Patient safety and the success rate of caries treatment undertaken by dental students, might be improved if students are better equipped to detect caries and prevent healthy tooth tissue from harm.

Conclusion:

This research has demonstrated that a new teaching tool may have positive effects on students' confidence in their ability to identify and correctly remove carious tissue without damaging the healthy tooth. The data collected in this pilot study was limited, but still demonstrates a promise of 3D-printed teeth as a supplementary learning tool, with further research necessary. Senior clinical dental students perceived the novel 3D-printed caries exercise positively, with 71.4% stating this would have better prepared them for clinical treatment over standard plastic teeth training. The quantified variance amongst students' cavity preparations, may suggest that a more robust representation of caries removal and more in-depth practice of tactile sensation is necessary in the dental school teaching curriculum, prior to students embarking on patient treatment, to ensure student development and patient treatment are both optimised.

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Table 1

	Strongly Agree	Agree	Neither	Disagree	Strongly Disagree
I felt fully prepared and clinically ready when treating my first carious lesion on clinic:	0	7	2	3	2
The 3D-printed carious teeth were a good simulation of tactile clinical caries removal:	4	5	4	1	0
The 3D-printed teeth would have better prepared me with respect to the clinical procedure, caries removal, compared to the standard plastic teeth training in labs:	5	5	3	2	0
Clinical lab teaching using the 3D-printed teeth would have reduced my stress and/or anxiety when	3	5	4	2	0

treating my first caries patient:					
	Very High	**High**	**Low**	**Very Low**	**Zero**
When I treated my first caries patient, my anxiety and stress levels were:	6	5	2	1	0

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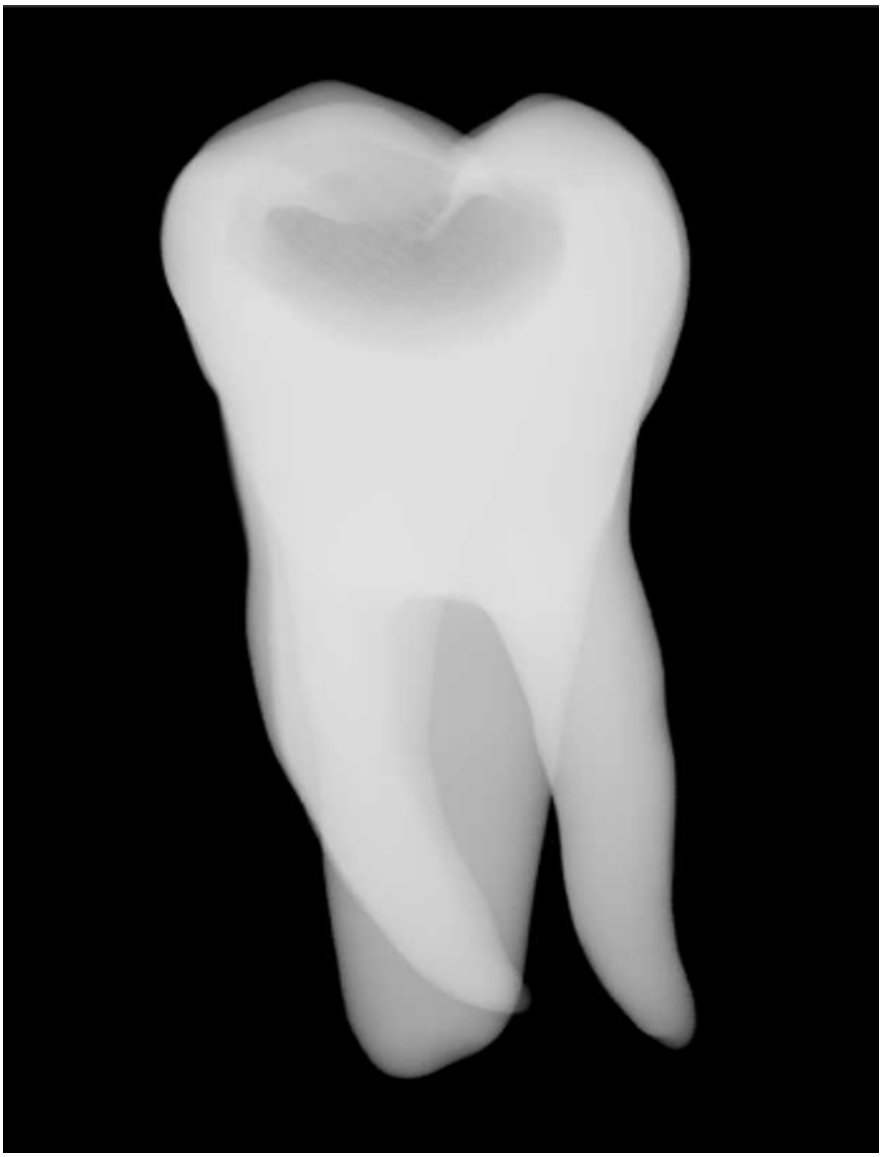

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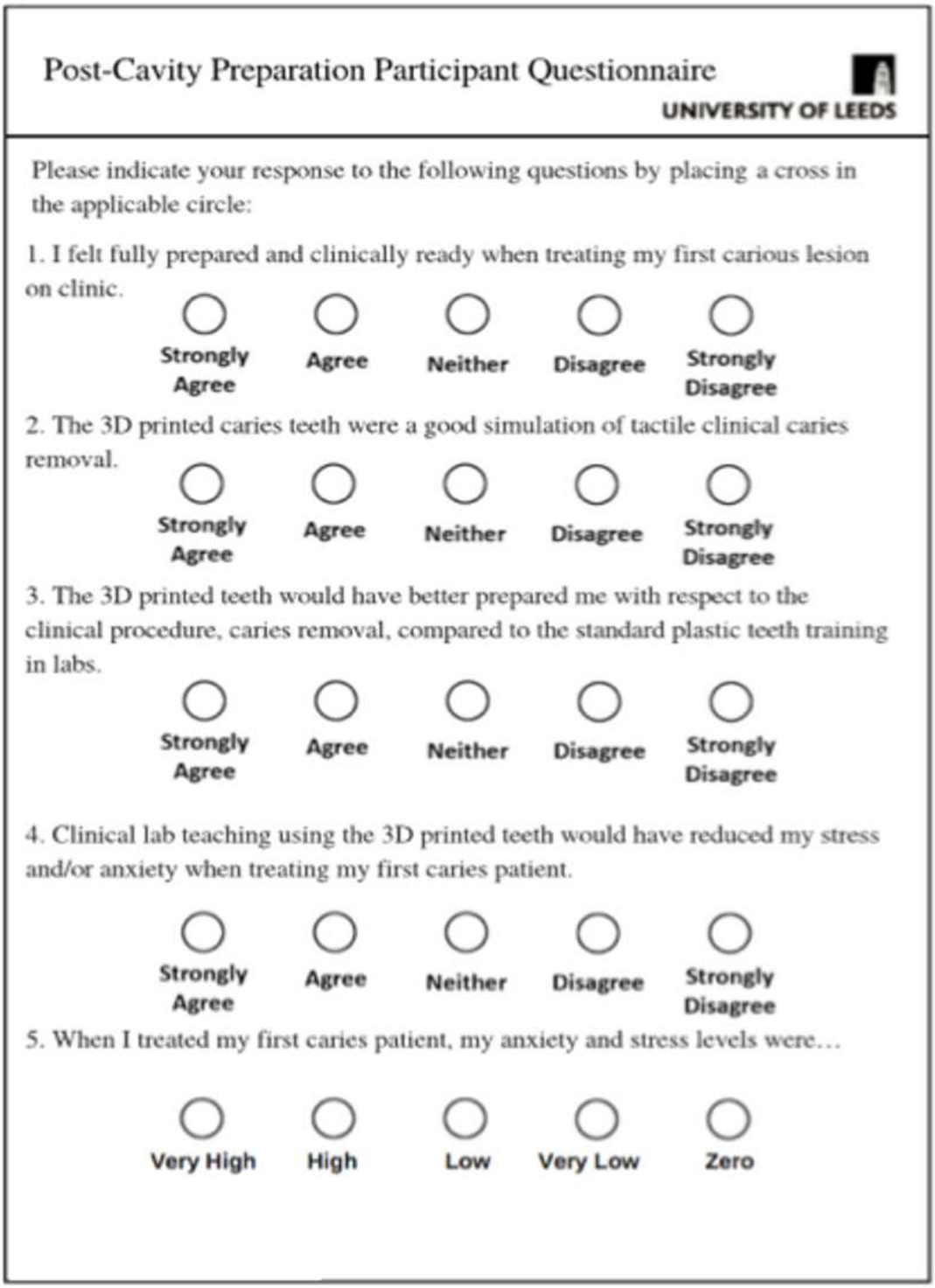

Post-Cavity Preparation Participant Questionnaire

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Please indicate your response to the following questions by placing a cross in the applicable circle:

1. I felt fully prepared and clinically ready when treating my first carious lesion on clinic.

Strongly Agree | Agree | Neither | Disagree | Strongly Disagree

2. The 3D printed caries teeth were a good simulation of tactile clinical caries removal.

Strongly Agree | Agree | Neither | Disagree | Strongly Disagree

3. The 3D printed teeth would have better prepared me with respect to the clinical procedure, caries removal, compared to the standard plastic teeth training in labs.

Strongly Agree | Agree | Neither | Disagree | Strongly Disagree

4. Clinical lab teaching using the 3D printed teeth would have reduced my stress and/or anxiety when treating my first caries patient.

Strongly Agree | Agree | Neither | Disagree | Strongly Disagree

5. When I treated my first caries patient, my anxiety and stress levels were…

Very High | High | Low | Very Low | Zero

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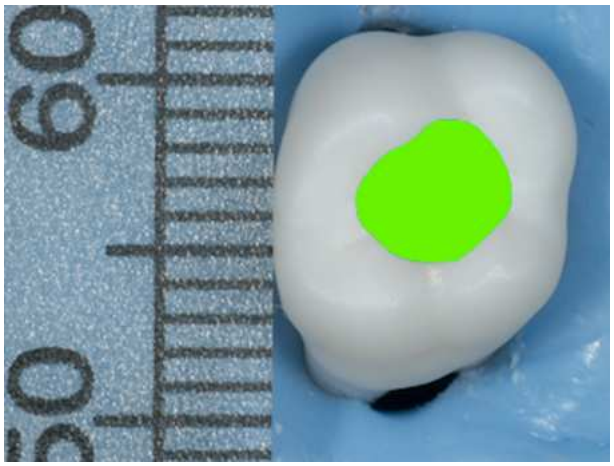

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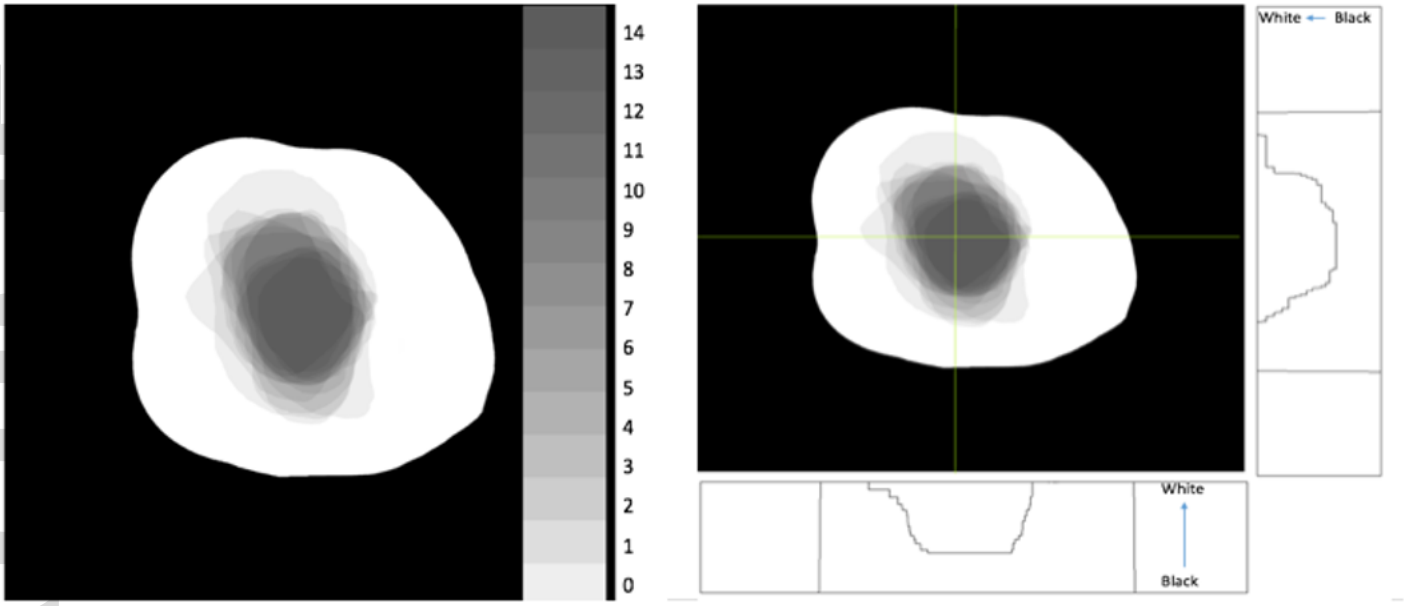

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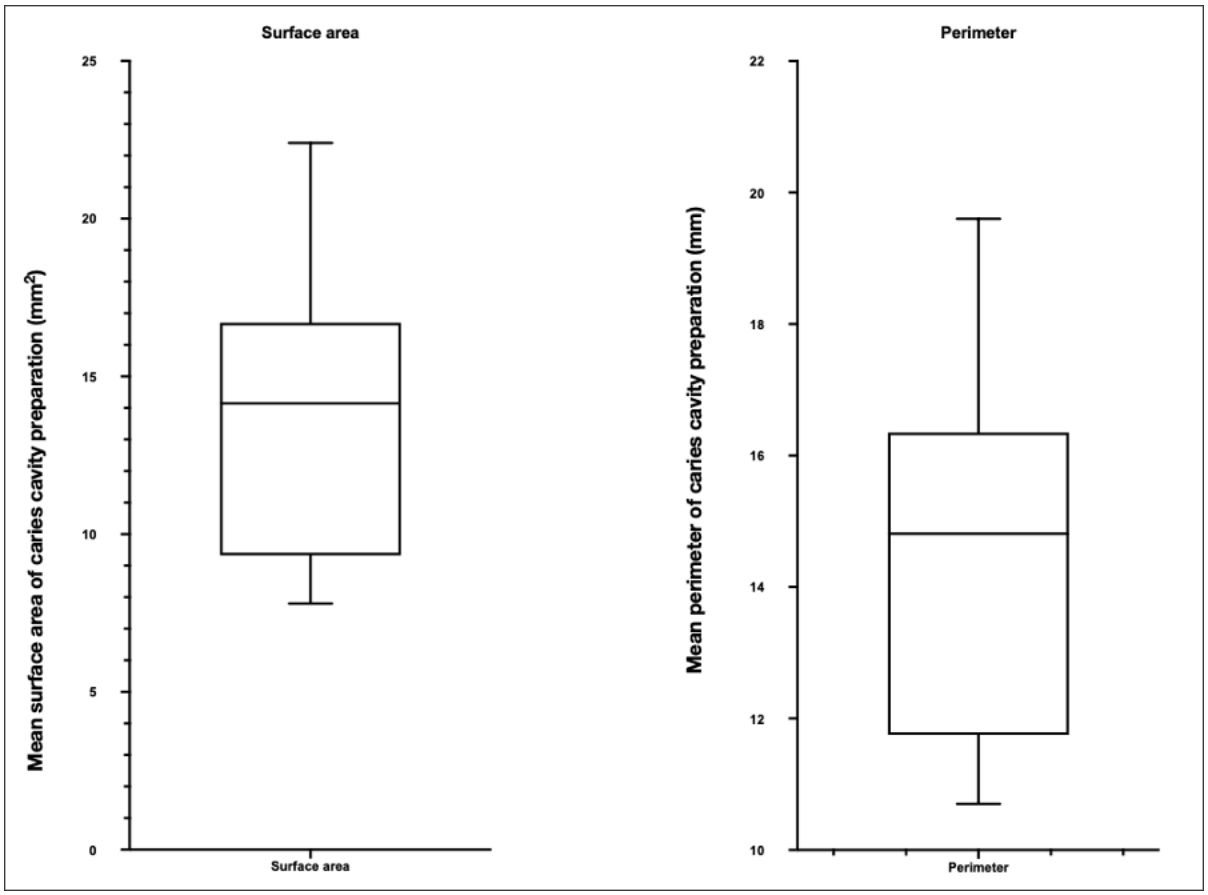

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