



ORIGINAL ARTICLE

Preclinical 3D-printed laboratory simulation of deep caries and the exposed pulp reduced student anxiety and stress, while increasing confidence and knowledge in vital pulp treatment

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Abstract

Aim: To evaluate the impact of a preclinical laboratory session using 3D printed teeth on dental student stress, anxiety, confidence and knowledge when treating deep caries and pulp exposure.

Methodology: This was a two-centre controlled study, with randomized distribution of students into two groups: a vital pulp treatment (VPT) lecture-only (control) group and a VPT-lecture combined with a VPT-laboratory (experimental) group. In both universities, preclinical students with endodontic or operative dentistry laboratory sessions could participate. All students were invited to the lecture. Two weeks later (timepoint-T1), both groups completed validated and bespoke questionnaires and scales to evaluate their stress (Stress-VAS), anxiety (STAI Trait [T] and State [S]), self-confidence and knowledge. Thereafter, only the experimental group attended the hands-on laboratory session demonstrating the techniques of selective caries removal and partial pulpotomy on a commercial 3D-printed tooth. Two weeks later (timepoint-T2), the participants from both groups repopulated the same questionnaires and VAS. The control group had the laboratory session after the completion of the study. The statistical analysis was performed with Statistica® (significance $p = .05$). The homogeneity between the two samples was checked by χ^2 and Student tests. Stress-VAS, STAI-S, confidence and knowledge scores were compared within each group, and between the two groups, at T1 and T2, with a repeated measures ANOVA test (+/–Tukey post-hoc test).

Results: The groups comprised 54 students each, with no statistical difference between the groups regarding demographic, academic data and STAI-T score. The two groups had no significant difference of Stress-VAS, STAI-S, confidence and knowledge scores at T1 while they presented a significant difference in stress, anxiety and confidence scores at T2, but with no significant difference in knowledge score. However, knowledge score, as other parameters, improved significantly between T1 and T2 in the experimental group.

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Conclusions: The addition of a laboratory session using 3D-printed teeth that simulated deep caries and pulp exposure management, significantly reduced the stress and anxiety of students and increased their confidence. Within the limitations of this study, the benefit of introducing new technology in increasing student confidence and reducing stress offers opportunity for educational improvement in the VPT and cariology areas.

KEYWORDS

deep caries, dental students, knowledge, laboratory simulation, stress, vital pulp treatment

INTRODUCTION

Dental caries in permanent teeth remains a prevalent disease with approximately two billion people affected worldwide (GBD 2017 Oral Disorders Collaborators et al., 2020). In response to advancing caries, the dentine–pulp complex reacts by a combination of inflammation and the promotion of mineralization (Cooper et al., 2010). As a result of this interplay, the pulp of an affected tooth exhibiting deep caries can recover if the microbial irritation is removed and the tooth is restored with a high-quality sealing restoration (Cooper & Smith, 2016; Mjör & Tronstad, 1974). Over the last 10 years, there has been a significant focus on the development of minimally invasive strategies aimed at supporting the vitality of the pulp by reducing the inflammatory insult (Bjørndal et al., 2019).

The concept of selective caries removal to soft dentine, in one or two stages, in an attempt to avoid pulp exposure (Bjørndal et al., 2017), was promoted by the International Caries Consensus Collaboration recommendations as well as the European Society of Endodontology (ESE) position statement (ESE, 2019; Innes et al., 2016; Schwendicke et al., 2016). These recommendations applied to cases of deep caries, defined as caries reaching the inner third or quarter of dentine, in a tooth with symptoms not greater than reversible pulpitis (ESE, 2019; Innes et al., 2016; Schwendicke et al., 2016). Recently, the American Association of Endodontists (AAE) released a position statement promoting complete caries removal in all cases of deep caries, an opinion that opposes the views of other consensus documents (AAE, 2021). If the pulp is exposed in teeth with deep, or extremely deep caries (defined as caries penetrating the entire thickness of dentine without a radiodense zone separating the lesion from the pulp), pulp capping, partial pulpotomy or full pulpotomy, with a hydraulic calcium silicate material is recommended; provided the tooth is asymptomatic, or exhibits symptoms indicative of reversible pulpitis (ESE, 2019). These pulp preservation approaches are supported by evidence highlighting that selective carious removal, and in cases of exposure, direct pulp capping with mineral trioxide aggregate (MTA), have

cost-effectiveness advantages over more invasive treatments such as root canal treatment (Emara et al., 2020).

A lack of consensus among dentists regarding the most appropriate way in which to manage deep caries and the exposed pulp has been highlighted (Careddu et al., 2021; Edwards et al., 2021), which may contribute to increased student anxiety and stress about the best way to manage pulp exposure (Chevalier et al., 2021). As a result, there is a need to improve education for dental students in this area. The treatment of deep caries by a one-stage selective removal approach is already implemented in the United States (US) undergraduate cariology curriculum, in addition to the two-stage (stepwise) and pulp capping techniques (Fontana et al., 2016), while the management of deep caries and vital pulp treatment (VPT) are listed as core competences in both general (Cowpe et al., 2010; Field et al., 2017) and endodontic (De Moor et al., 2013) undergraduate curricula. There remains, however, considerable scope for educational improvement and innovation. A survey of US Cariology faculty members revealed a lack of an evidence-based philosophy with regards to the teaching of deep carious tissue removal (Nascimento et al., 2017). When encountering this clinical scenario, half of the respondents reported that the floor of the cavity had to be ‘hard’, while the others were satisfied with a ‘leathery’ floor to the cavity (Nascimento et al., 2017). Furthermore, in a recent study, it was demonstrated that VPT and the use of hydraulic calcium silicate materials were part of the curriculum in 93% and 80% of United Kingdom (UK) universities respectively during postgraduate endodontic training, but only in 60% and 40% of UK universities during undergraduate preclinical training (Al Raisi et al., 2019). An investigation in another European country, highlighted that only a small volume of time was dedicated to the teaching of VPT and modern endodontic materials in Spanish universities (Segura-Egea et al., 2021).

Despite an increased focus on student feedback, course satisfaction and support (Field et al., 2017), there is a paucity of studies assessing student anxiety, stress and confidence in the management of deep caries and the exposed pulp. A recent study highlighted that students were confident in

their ability to treat caries; however, the work did not specifically address cases of deep caries (Rajan et al., 2020), while another study highlighted student's preference for carrying out selective carious removal to soft dentine in cases of deep caries, despite a lack of experience with this technique (Chevalier et al., 2021). Notably, selective carious removal helped to decrease student stress when unexpectedly dealing with a pulp exposure. In the event of pulp exposure, students reported increases in their stress levels, but considered pulp capping an easier technique to perform than partial pulpotomy. They suggested that a preclinical laboratory simulation in this area could improve education and potentially decrease their stress levels during clinical treatment (Chevalier et al., 2021).

In order to address this lack of pre-clinical training, as well as the limited experience students have with these techniques, a preclinical laboratory practical simulation session addressing selective carious removal and partial pulpotomy was proposed. The principal objective of this study was to evaluate the impact of a preclinical laboratory teaching using commercially available 3D-printed teeth on student stress, anxiety, confidence and knowledge when performing deep caries management and pulp exposure. An additional aim was to assess if other parameters including gender, students level of general anxiety and university location influenced the impact of the session. The final aim was to evaluate how students appreciated the teaching innovation.

MATERIAL AND METHODS

This study was designed as a two-centre parallel controlled study, with a randomized distribution of students into two groups: a VPT lecture-only group (control group) and a VPT lecture group combined with a VPT lab session (experimental group).

The VPT lab session comprised of two steps. The first step involved carrying out selective carious removal to soft dentine on a commercially available 3D-printed tooth (Right Nao), which had a deep carious lesion and simulated pulp tissue. The second step consisted of performing a partial pulpotomy on the same tooth.

The impact of implementing this preclinical laboratory session on stress, anxiety, confidence and knowledge was evaluated by a range of assessments and questionnaires among preclinical undergraduate students in two European centres.

Ethical considerations

This study was carried out in Brest Dental University (BDU) and in the School of Dental Sciences, Trinity College Dublin

(TCD) and was approved by both the Ethics Committee of Brest University Hospital (N° B2021CE.09) and by the Ethics Committee of Dublin Dental University Hospital (DDUH) (N° 2019-11-01). Prior to engaging in the study, all potential participating students were informed of the nature of the study, allowed to ask questions, and asked to consider their inclusion, before completing a consent form if they voluntarily agreed to take part in the study.

Participants

All preclinical dental science students who were scheduled to have preclinical laboratory simulation sessions organized by the Department of Restorative Dentistry and Endodontics in the BDU and by the Endodontic staff of the Division of Restorative Dentistry and Periodontology in the School of Dental Sciences, TCD, were invited to participate the study. Depending on the respective curricula and timetables in each jurisdiction, this dictated that students in second and third years in BDU and students in second year in TCD could participate. Only students who expressed an interest in participating and signed consent were included in the study. All students who refused to sign the consent or were absent during the preclinical session, or who did not complete one or more surveys were excluded from the survey and project.

Randomisation

Within each academic year group in both dental schools, students were randomly assigned to the control or the experimental group using an online computer-generated number (www.randomizer.org) and block randomisation technique.

Sample size calculation

Variation in student stress levels measured by a 0–10 visual analogue scale (VAS) was considered the primary outcome and basis for the study power calculation. The number of subjects was determined in order to guarantee a power of 80% for the demonstration of a clinically meaningful Stress-VAS difference of 1.5 points between the groups after the lab-session of the tested group, with a standard deviation of approximately 2 points (previously determined in a pilot study). With these assumptions, a total of 29 subjects per group accounting for potential drops outs (58 in total) was deemed an adequate number.

Intervention/study design

Prior to the preclinical lab session

The students were randomized into two groups by an online block randomisation tool (www.randomizer.org). All students (included and non-included) were invited to participate in a Zoom® lecture about the management of

deep caries and the exposed pulp. This lecture was based on the recent ESE position statement regarding the management of deep caries and associated recommendations (ESE, 2019). It was prepared in a collaborative process between endodontic leads in both universities (VC, HD). In BDU and TCD the lecture presented to the students was given by the same dental individual (VC). The first evaluation (for both groups) and the preclinical laboratory

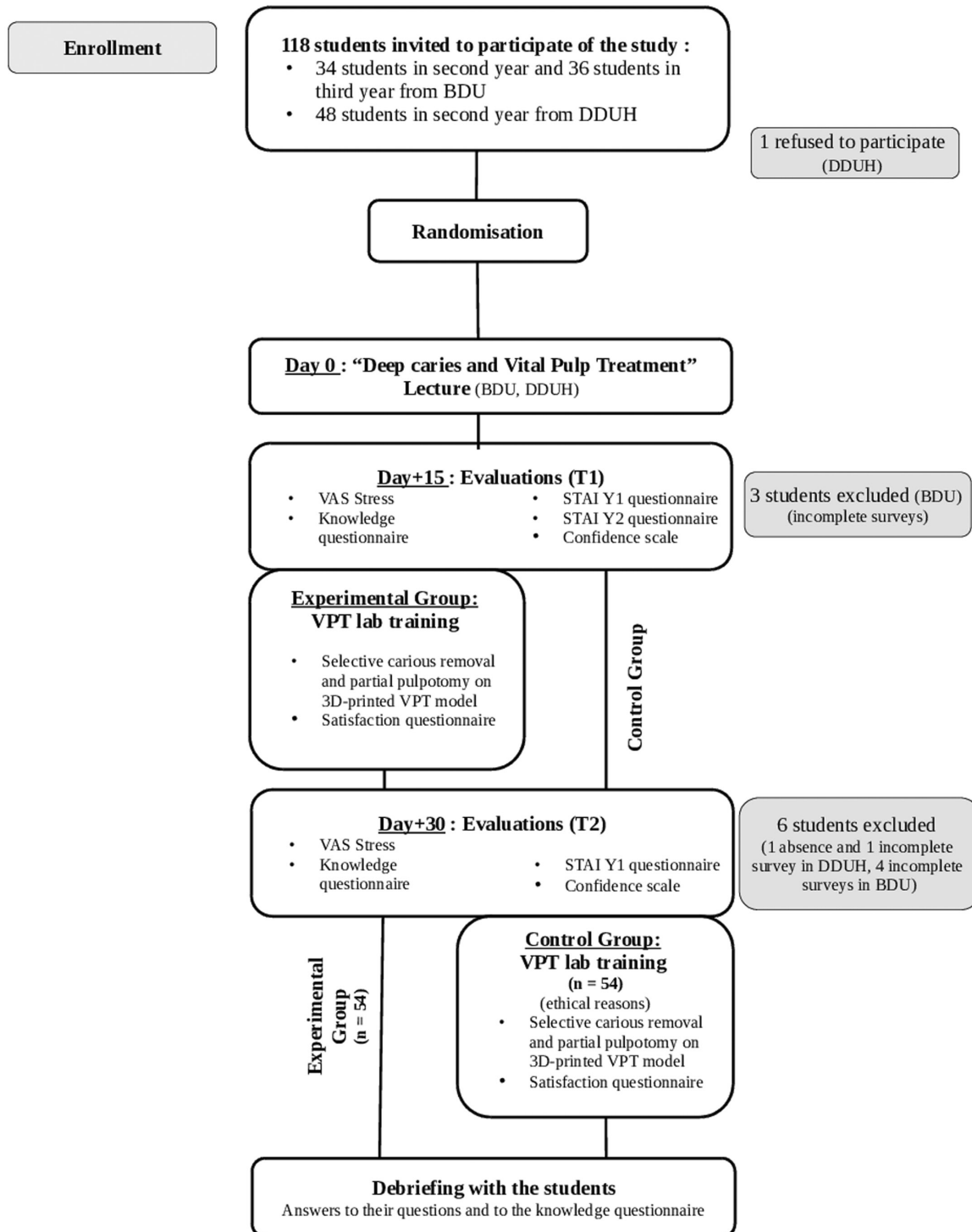


FIGURE 1 Study design

session for the experimental group occurred 2 weeks after the lecture (Figure 1).

Preclinical lab session

Immediately before beginning the laboratory session (defined as T1), all the included students (from both groups) completed the assigned questionnaires and VAS to evaluate their stress, anxiety, self-confidence and knowledge. Thereafter, only the experimental group attended the VPT laboratory session (Figure 1).

First, a clinical case describing a mandibular molar with signs and symptoms indicative of reversible pulpitis due to deep caries was shown to the students. Questions were asked about diagnosis and treatment. The answers were discussed with the group for the clinical case. Thereafter, students performed the one-stage selective removal to soft dentine under rubber dam on the Naodent® (Right-Nao) simulated tooth (3D-printed resin tooth with deep carious lesion and gelatinous pulp tissue) using a step-by-step teaching method. They were instructed to avoid pulp exposure by carefully leaving a thin layer of residual soft dentine on the pulpal aspect of the cavity. Once selective carious removal was complete and checked by the supervisors, the students placed a 3–4 mm thick layer of a hydraulic calcium silicate material (Biodentine®; Septodont) over the deep dentine.

In a second exercise, a new clinical scenario was presented and discussed and this led the students to remove the biomaterial and to perform a non-selective (complete) caries removal. This invariably resulted in pulp exposure. Pulpal bleeding was simulated by the exudate of red liquid from the gelatinous pulp tissue. After simulation of pulp wound lavage with 2.5% sodium hypochlorite solution, a partial pulpotomy procedure was carried out with the removal of approximately 3 mm of pulp tissue, disinfection, haemostasis and placement of a hydraulic calcium silicate (Biodentine®) onto the exposed pulp.

At the completion of the lab session, a training evaluation survey critically assessing the session was distributed to every member of the experimental group.

After the preclinical lab session

Two weeks later (timepoint-T2), the participants from both groups repopulated the questionnaires and visual scales to evaluate their stress, anxiety, confidence and knowledge regarding VPT. For reasons of ethical and educational standardization, the control group also benefited from the laboratory session after the end of the study and completed the training evaluation survey at the end of the VPT lab session.

Assessment tools

Stress and anxiety

To evaluate student anxiety, the validated Spielberger STAI State (S) and Trait (T) questionnaire (Spielberger, 1983; Spielberger, 1989), with each STAI (S and T) questionnaire containing 20 items rated one to four, was used. The higher the score, the higher the anxiety. The STAI-T scale characterizes anxiety, by assessing the way subjects feel in general. This questionnaire was distributed to all the included students to investigate and ensure that the two groups were similar in terms of general stress (Figure 1). In the general population, the mean Trait anxiety score is reported as 34.8 for females and 34.9 for males (Spielberger, 1983). Above a score of 47, women and men are considered anxious (McDowell, 2006). The STAI-S scale is related in this case to the feelings experienced before treatment of a deep carious lesion with risk of pulp exposure. A clinical photograph and accompanying radiograph were shown to the students and they were asked to report the anxiety they would experience in this clinical situation, at T1 and T2. In general, for STAI-S, the mean score is 35.2 for females and 35.7 for males (Spielberger, 1983).

Stress was assessed using a stress visual analogic scale (Stress-VAS). The VAS is based on a 10-cm scale on which subjects were asked at T1 and T2 to score the level of stress they would experience before deep caries removal with risk of pulp exposure (as with STAI-S) from 0 (no stress) to 10 (worst possible stress). VAS to analyse stress has previously been validated with a threshold at 6 defined as the point where a person can be considered stressed (Lesage et al., 2012; Lesage & Berjot, 2011).

Confidence

A bespoke confidence questionnaire with 10 included items (Table 1) was constructed by two members of academic staff, one each from BDU and TCD. The confidence was assessed from 0 (=no confidence) to 10 (=total confidence) for each of the 10 questions by using a Confidence-VAS, at T1 and T2. The mean score for the 10 questions was calculated for each student (scored out of 10).

Knowledge

A multiple-choice questionnaire with 10 items (Table 2), was constructed by the same academics as the confidence questionnaire. It aimed to evaluate the student's theoretical knowledge about VPT at T1 and T2. Each answer was

TABLE 1 Confidence questionnaire

Questions	Group	T1	T2
1 I feel confident managing carious tissue removal.	Experimental group	5.29 ± 2.09	6.79 ± 1.93
	Control group	5.46 ± 2.54	5.26 ± 2.64
2 I can easily evaluate my work in Cariology.	Experimental group	4.12 ± 1.92	5.85 ± 2.06
	Control group	4.50 ± 2.30	4.63 ± 2.34
3 I feel confident when managing a deep carious lesion.	Experimental group	3.58 ± 2.33	6.08 ± 2.15
	Control group	4.20 ± 2.35	3.81 ± 2.12
4 I feel confident when managing an extremely deep carious lesion.	Experimental group	2.70 ± 1.87	5.35 ± 2.13
	Control group	3.25 ± 2.18	2.94 ± 2.03
5 I am able to readily evaluate the position of the bur inside the tooth (pulp distance, depth of the cavity) during the procedure.	Experimental group	4.62 ± 2.25	5.91 ± 2.23
	Control group	4.37 ± 2.59	4.21 ± 2.25
6 I feel confident when performing selective carious removal to soft dentine in a patient.	Experimental group	4.06 ± 2.60	6.19 ± 2.20
	Control group	4.25 ± 2.53	4.04 ± 2.57
7 I feel confident when performing a partial pulpotomy.	Experimental group	3.06 ± 2.24	5.59 ± 2.15
	Control group	2.92 ± 2.19	2.98 ± 2.28
8 I feel confident placing the rubber-dam.	Experimental group	7.80 ± 2.28	8.55 ± 1.52
	Control group	7.85 ± 2.25	7.73 ± 1.91
9 I feel confident when placing a hydraulic calcium silicate (Biodentine).	Experimental group	4.02 ± 2.59	7.83 ± 1.81
	Control group	4.45 ± 2.60	4.29 ± 2.69
10 I feel confident obtaining haemostasis after pulp exposure.	Experimental group	3.22 ± 2.33	6.68 ± 2.23
	Control group	3.36 ± 2.30	3.57 ± 2.72

awarded one mark, with each student obtaining a final score out of 10.

Training evaluation questionnaire

A satisfaction evaluation survey with 15 items (Table 3) was constructed. Fourteen items were closed-ended VAS-type questions rated between 0 (=totally disagree) and 10 (=totally agree) and the last question was an open question to permit comments.

Statistical analysis

The statistical analysis was performed with Statistica® (version 14) (Tibco) and checked for normality of the data distribution. The two samples (experimental and control groups) were compared in terms of gender, year of study and the universities' location by a χ^2 test, and in terms of STAI-T score, as well as age by a Student independent *t*-test. The significance level was set at $p \leq .05$. Each of the main parameters (Stress-VAS score, STAI-S score, confidence score and knowledge score) was compared within each group, and between the two groups, at T1 and T2, with a repeated measures ANOVA test, followed by a Tukey post-hoc test, if required.

The effect of gender, STAI-T and dental school location on various principal parameters at T1 for the whole sample was analysed by a Student *t*-test. A correlation test (Correlation Matrices Test) was made at T1 for the entire sample between the Stress-VAS and the STAI-S. The effect of gender, STAI-T and school location on the evolution of the main parameters (Stress-VAS score, STAI-S score, confidence score and knowledge score) between T1 and T2 was analysed by a repeated measures ANOVA test (+/- Tukey post-hoc test) in the experimental group and separately in the control group.

RESULTS

Group demographics

Ten students were excluded for the following reasons; refusal ($n = 1$), absence from a session ($n = 1$) and incomplete surveys ($n = 8$) (Figure 1), leaving a total sample of 108 students, with 54 students in each group. The experimental group comprised 23 students from TCD (second year) and 31 from BDU (15 second years and 16 third years). The control group consisted of 22 students from DDUH (second year) and 32 from BDU (16 second years and 16 third years). The mean ages were 21.44 (± 3.24) years in the

TABLE 2 Knowledge questionnaire

Items	Group	T1	T2
1 Definition of “deep carious lesion”	Experimental group	0.43 ± 0.43	0.50 ± 0.37
	Control group	0.37 ± 0.39	0.43 ± 0.39
2 Treatment of a deep caries with an irreversible pulpitis	Experimental group	0.57 ± 0.50	0.48 ± 0.50
	Control group	0.44 ± 0.50	0.43 ± 0.50
3 Definition of “extremely deep carious lesion”	Experimental group	0.46 ± 0.36	0.47 ± 0.40
	Control group	0.50 ± 0.40	0.49 ± 0.37
4 Definition and steps of a selective caries removal to soft dentine	Experimental group	0.52 ± 0.50	0.57 ± 0.50
	Control group	0.61 ± 0.49	0.67 ± 0.48
5 Definition of “soft dentine”	Experimental group	0.57 ± 0.34	0.65 ± 0.36
	Control group	0.59 ± 0.30	0.64 ± 0.28
6 Way of performing a selective carious removal to soft dentine	Experimental group	0.70 ± 0.46	0.85 ± 0.36
	Control group	0.80 ± 0.41	0.78 ± 0.42
7 Type of carious removal (complete/selective) and VPT to perform in case of a reversible pulpitis with a pulp exposure	Experimental group	0.13 ± 0.24	0.15 ± 0.27
	Control group	0.22 ± 0.34	0.08 ± 0.21
8 Recommended material for a direct pulp capping or a pulpotomy	Experimental group	0.48 ± 0.48	0.51 ± 0.48
	Control group	0.66 ± 0.42	0.55 ± 0.45
9 Recommended treatment following a pulp exposure on a vital asymptomatic tooth	Experimental group	0.22 ± 0.36	0.39 ± 0.43
	Control group	0.26 ± 0.36	0.36 ± 0.42
10 Management of a pulp exposure during a deep carious removal	Experimental group	0.45 ± 0.40	0.56 ± 0.43
	Control group	0.36 ± 0.42	0.35 ± 0.43

Abbreviation: VPT, vital pulp treatment.

experimental and 21.81 (± 2.95) years in the control group. There were 34 females and 20 males in the experimental group and 37 females and 17 males in the control group. The baseline STAI-T score demonstrated that, in general, the individuals in both groups had moderate levels of anxiety, with 38.83 (± 9.54) in the experimental group and 39.33 (± 10.61) in the control group. There was no statistical difference in the profile of the groups in terms of gender ($p = .54$), year of study ($p = 1.0$), university location ($p = .85$), STAI-T score ($p = .8$) and age ($p = .54$).

Comparisons between the groups at T1 and T2

The means and standard deviations of Stress-VAS, STAI-S score, confidence questionnaire and knowledge questionnaire for both groups at T1 and T2 along with results from the ANOVA repeated tests are presented in Table 4. There was no significant difference between the two groups in terms of Stress-VAS ($p = .8$), STAI-S ($p = 1.0$), confidence scores ($p = .86$) and knowledge scores ($p = .84$) at T1 (Table 4). Both groups reported that they generally felt quite stressed and anxious in the clinic when managing deep caries, according to their Stress-VAS and STAI-S at T1. There

was a significantly lower stress and anxiety (Stress-VAS [$p = .007$] and STAI-S [$p = .01$]) in the experimental group at T2 in comparison with the control group (Table 4). There was no difference in confidence and knowledge scores between the two groups at T1, with similar low-to-moderate levels of confidence and a feeling that their knowledge was insufficient (Table 4). Confidence was significantly higher in the experimental group in comparison with the control group at T2 ($p < .001$), while knowledge was not significantly increased in the experimental group in comparison with the control group ($p = .73$) (Table 4).

Comparisons in each group between T1 and T2

Differences in Stress-VAS, STAI-S, confidence score between T1 and T2 were significant in the experimental group (with $p < .001$ for the three parameters), but not in the control group (Table 4). In the experimental group at T2, the questions that were associated with an increase of confidence, greater than or equal to a 25% change, were questions 3, 4, 7, 9 and 10; which were related to deep (and extremely deep) caries removal, partial pulpotomy, placement of a hydraulic calcium silicate cement and haemostasis after pulp exposure (Table 1).

TABLE 3 Training evaluation questionnaire

	Questions	Mean \pm standard deviation
1	I liked this lab training session	9.18 \pm 0.95
2	The topic of this lab training was interesting	9.23 \pm 0.83
3	The duration of the lab training was satisfactory	8.41 \pm 1.81
4	This lab training is adapted to my academic level	8.37 \pm 1.64
5	This lab training was useful	9.29 \pm 0.83
6	The 3-D printed model (tooth) enabled me to discover the texture of carious tissue and the bleeding of a vital tooth	9.21 \pm 1.09
7	This simulation helped to consolidate my knowledge	9.09 \pm 1.27
8	This simulation allowed me to acquire new knowledge	9.20 \pm 1.00
9	This lab training has enabled me to develop my skills regarding the management of the deep caries and VPT	9.31 \pm 0.78
10	This lab training has enabled me to develop my theoretical understanding regarding the management of the deep caries and VPT	9.24 \pm 0.77
11	This lab training has enabled me to develop dexterity in the management of deep caries and VPT	8.92 \pm 1.37
12	I would like to try this kind of lab training in a different subject or speciality	9.31 \pm 1.17
13	This lab training will influence my future practice	8.73 \pm 1.42
14	I would recommend this preclinical lab to other students	9.46 \pm 0.76
15	Do you have comments or suggestions?	

Abbreviation: VPT, vital pulp treatment.

The difference in knowledge scores between T1 and T2 was significant ($p = .05$) in the experimental group and not significant in the control group (Table 4). In the experimental group at T2, the questions that recorded greater than or equal to a 10% increase in their correct answer rate, was question 6 (related to selective carious removal) and questions 9 and 10, which related to pulp exposure and its management (Table 2).

Effect of gender, university location and STAI-T on the stress, anxiety, confidence and knowledge scores at T1

Results at T1 for the entire sample rated to gender, location of the university and STAI-T score are highlighted in Table 5. At T1, female anxiety and stress were significantly higher than male anxiety and stress ($p = .03$ and $p = .04$ respectively) (Table 5), while female confidence was not significantly different from male confidence ($p = .19$). Female mean knowledge score was not significantly different from men ($p = .43$) (Table 5).

Trinity College Dublin students were significantly more anxious and stressed than those in Brest (with respectively $p = .007$ and $p = .04$). While the confidence of students in

TCD was not shown to be significantly lower ($p = .06$), it was close to the significance level. The mean knowledge of BDU students in the subject area was significantly higher than that of TCD students ($p < .001$) (Table 5).

Students who were generally more anxious (STAI-T ≥ 47), presented with a significantly higher anxiety and stress at T1 (STAI-S [$p = <.001$] and Stress-VAS [$p = .003$]) and a significantly lower confidence ($p = .005$). However, the knowledge score was not significantly different according to the STAI-T group at T1 ($p = .31$) (Table 5). The result of the correlation test on the entire sample at T1 highlighted a good correlation between the Stress-VAS and the STAI-S ($r = .70$).

Effect of gender, university location and STAI-T on the stress, anxiety, confidence and knowledge scores in the experimental and control groups, between T1 and T2

In the experimental group, gender had no influence on the development of Stress measured by VAS ($p = .88$), of anxiety indicated by STAI-S ($p = .18$), of confidence score ($p = .81$) as well as knowledge score ($p = .12$) (Table 6).

TABLE 4 Results per group and per time of the main parameters mean variation and standard deviation and *p* values (ANOVA repeated test, with *p* = .05) (Conf. = confidence; know. = knowledge)

	STAI-S (T1)	STAI-S (T2)	Intra-group <i>p</i> -Value	Stress-VAS (T1)	Stress-VAS (T2)	Intra-group <i>p</i> -Value	Conf. Score (T1)	Conf. Score (T2)	Intra-group <i>p</i> -Value	Know. Score (T1)	Know. Score (T2)	Intra-group <i>p</i> -Value
Experimental group	44.54 ± 10.33	38.48 ± 8.32	<.001	5.09 ± 2.22	3.83 ± 2.25	<.001	4.22 ± 1.57	6.44 ± 1.54	<.001	4.52 ± 2.06	5.13 ± 1.80	.05
Control group	44.93 ± 10.81	44.44 ± 11.38	.95	5.50 ± 2.35	5.27 ± 2.15	.84	4.48 ± 1.74	4.36 ± 1.78	.84	4.81 ± 1.80	4.77 ± 1.50	1.0
Intergroup <i>p</i> -Value	1.0	.01		.8	.007	.84	.86	<.001		.84	.73	

In the experimental group, the location of the university school had no influence on the development of Stress measured by VAS (*p* = .73), STAI-S score (*p* = .98), or confidence score (*p* = .10). However, TCD students acquired greater knowledge (*p* = .01), with a significant difference between T1 and T2 (*p* = .002), than BDU students, who demonstrated no significant difference in knowledge score between T1 and T2 (*p* = .92) (Table 6).

In the experimental group, students that were generally more stressed (STAI-T ≥ 47) demonstrated a similar development of their STAI-S (*p* = .45), Stress-VAS (*p* = .39), confidence (*p* = .29) and knowledge (*p* = .85) scores, compared with students who were generally less stressed (STAI-T < 47) (Table 6).

In the control group, gender, university location and STAI-T had no significant influence on the variation of stress, anxiety, confidence and knowledge scores (*p* > .05).

Training evaluation by the students

The majority of students reported that they enjoyed the session (Table 3) and considered it useful as a simulation of caries removal and was particularly useful for deep caries removal. Other recurrently positive comments in the students' qualitative analysis were:

'I really enjoyed this simulation. It helped me get a better idea of what I would expect on a real tooth'.

'I loved the 3-D printed tooth!'

'This was really fun. I really enjoyed the fact that it was taken through step by step, including teaching us how to diagnose and choose the treatment'.

However, there were also some negative comments with selected second years in BDU highlighting that the session occurred too early in their curriculum. Other students would have preferred to have sufficient time to carry out the coronal restoration of the tooth in the session. Other critical comments, which occurred frequently were:

'It would be useful if we could place the practice tooth into our mannequin head to improve dexterity'.

TABLE 5 Comparison of mean score (\pm SD) of stress, confidence and knowledge at T1 according to gender, school location and anxiety trait ($p = .05$)

At T1	STAI-S	Stress-VAS	Confidence score	Knowledge score
Female	46.31 \pm 9.63	5.64 \pm 2.16	4.19 \pm 1.57	4.77 \pm 1.81
Male	41.70 \pm 11.59	4.66 \pm 2.41	4.64 \pm 1.78	4.46 \pm 2.15
Inter-gender <i>p</i> Value	.03	.04	.19	.43
TCD	47.96 \pm 10.88	5.89 \pm 2.60	3.98 \pm 1.81	3.62 \pm 1.43
BDU	42.43 \pm 9.71	4.93 \pm 2.00	4.60 \pm 1.50	5.42 \pm 1.90
Inter-university <i>p</i> Value	.007	.04	.06	<.001
STAI-T \geq 47	52.63 \pm 7.82	6.54 \pm 1.73	3.52 \pm 1.30	4.31 \pm 1.63
STAI-T < 47	42.48 \pm 10.14	4.93 \pm 2.31	4.59 \pm 1.67	4.77 \pm 2.01
Inter-STAI-T <i>p</i> Value	<.001	.003	.005	.31

Abbreviations: BDU, Brest Dental University; TCD, Trinity College Dublin.

TABLE 6 Experimental group results at T1 and T2 for the principal parameters (STAI-S, VAS-stress, confidence, knowledge) highlighting mean variation and standard deviation (according to gender, school location and anxiety trait [STAI-T]) and *p* values (ANOVA repeated test, with $p = .05$)

	Experimental group							
	STAI-S		VAS-stress		Confidence		Knowledge	
	T1	T2	T1	T2	T1	T2	T1	T2
Female	45.94 \pm 10.79	39.00 \pm 8.40	5.43 \pm 2.41	4.13 \pm 2.28	3.99 \pm 1.43	6.18 \pm 1.54	4.67 \pm 1.97	5.03 \pm 1.73
Male	42.15 \pm 9.26	37.60 \pm 8.33	4.53 \pm 1.80	3.32 \pm 2.15	4.61 \pm 1.76	6.88 \pm 1.46	4.26 \pm 2.23	5.29 \pm 1.95
T1-T2*gender <i>p</i> -Value	.18		.88		.81		.12	
Dublin	48.39 \pm 10.00	42.30 \pm 7.75	5.77 \pm 2.24	4.36 \pm 2.42	3.84 \pm 1.58	6.36 \pm 1.62	3.07 \pm 1.10	4.26 \pm 1.45
Brest	41.68 \pm 9.77	35.65 \pm 7.66	4.66 \pm 2.13	3.48 \pm 2.10	4.50 \pm 1.54	6.49 \pm 1.50	5.60 \pm 1.94	5.77 \pm 1.77
T1-T2*location <i>p</i> -Value	.98		.73		.10		.01	
STAI-T \geq 47	52.64 \pm 6.90	45.27 \pm 5.90	6.13 \pm 1.26	4.30 \pm 2.05	3.58 \pm 0.94	6.13 \pm 1.44	4.01 \pm 1.42	4.70 \pm 1.82
STAI-T < 47	42.47 \pm 10.09	36.74 \pm 7.99	4.84 \pm 2.34	3.71 \pm 2.30	4.38 \pm 1.67	6.52 \pm 1.57	4.65 \pm 2.19	5.24 \pm 1.80
T1-T2*STAI-T <i>p</i> -Value	.45		.39		.29		.85	

'I would have liked to have enough time to place the composite definitive restoration in the session'.

'It would be useful to attempt multiple times on multiple teeth'.

DISCUSSION

Recent research recommends performing selective carious removal to prevent pulp exposure in cases of deep caries (Barros et al., 2020) and partial pulpotomy, if the pulp

is exposed and the symptoms are not severe (ESE, 2019; Schwendicke et al., 2016). Paradoxically, students describe difficulties in carrying out both techniques, specifically with regard to the volume and the surface characteristics of the dentine to be retained in cases of selective caries removal and the quantity of pulp tissue removal, in cases of partial pulpotomy. They also highlight a lack of hands-on training in this area, which reduces their confidence (Chevalier et al., 2021).

In an attempt to address these concerns, a preclinical laboratory class was designed as a practical educational training session for students to carry out selective carious removal and partial pulpotomy. The reasons for selecting a

laboratory session included the fact that, training on simulated dental models has played a key role in dental education for more than 100 years (Perry et al., 2015) and remains a key component of the dental educational armamentarium, particularly in the skills required for endodontics and operative dentistry (Al Raisi et al., 2019; Segura-Egea et al., 2021; Tikhonova et al., 2018). Laboratory simulation sessions stimulate the development of specific psychomotor skills and generate mental and physical routines for performing dental treatment, prior to moving to the clinic (Perry et al., 2015; Widbiller et al., 2018). These laboratory sessions rely on a student-centred-approach (Hesson & Shad, 2007; Liu et al., 2019) that stimulates several memory processes (visual, tactile and auditory memories), which are important for the learning process (Shams & Seitz, 2008). In simulated practice, the learning process can be facilitated using an incremental or step-by-step method during the laboratory training session, as this has been shown to be effective for optimal learning (Liu et al., 2019; Yuan et al., 2020). Finally, a laboratory session was selected after feedback from students, and dental practitioners, who consider it a good educational tool to improve their confidence and practice for endodontic and restorative procedures (Chevalier et al., 2021; Hattar et al., 2021; Haug et al., 2021).

A considerable challenge when planning laboratory teaching of deep caries and exposed pulp is the absence of a tooth model that accurately simulates the clinical situation. Within this study, natural teeth were first considered, but excluded due to issues of infection control (Qualtrough, 2014), lack of available teeth, inability to standardize caries depth and an absence of pulpal bleeding due to necrosis. 3D printed teeth were then considered, not only as they are new educational tools, but also because they simulate the clinical reality in an identical manner for each student (Marty et al., 2019; Reymus et al., 2019). Feedback has highlighted that they are appreciated by undergraduate students due to their limitless availability and educational equality that standardization brings (Reymus et al., 2019). A tooth model simulating a deep carious lesion was developed specifically for pulpotomy training from a Cone Beam Computed Tomography (CBCT) scan of a molar tooth (Marty et al., 2019). The commercial tooth (Right-Nao) model employed in this study adopted a similar approach.

Biodentine® (Septodont) was selected as the biomaterial of choice, because it is indicated for both selective removal and partial pulpotomy. Biodentine® (Septodont) exhibits similar clinical outcomes to MTA for a full pulpotomy procedure, but with less discolouration (Abuelniel et al., 2020). Questionnaire-based research has highlighted that adoption of hydraulic calcium silicate materials for VPT procedures is poor in general dental practice,

as a result of high cost and lack of training in its use (Chin et al., 2016). Implementing educational initiatives to encourage more widespread use would be advantageous, as these materials have been shown to produce a more predictable outcome compared with traditional materials, such as calcium hydroxide (Chin et al., 2016).

The preclinical laboratory session in this study had a positive impact on the participants in terms of a reduction in their anxiety and stress levels, as well as improved confidence. In addition, the experimental and control groups demonstrated statistically significant differences within the experimental group from T1 to T2. This underlines one of the advantages of a practical laboratory session over a didactic lecture, or demonstration that has been highlighted with other medical, or dental studies, where a significant increase in confidence in their technical skills was observed after hand-on courses (Buerkle et al., 2013; López-Cabrera et al., 2017).

Although the preclinical laboratory session was effective in reassuring students, the lack of knowledge acquisition was surprising and disappointing, with no significant difference in knowledge level between the experimental and control groups at T2, despite a significant increase in knowledge in the experimental group between T1 and T2. A potential explanation is that previous research has shown the impact of laboratory sessions on theoretical knowledge to be uncertain, with one study investigating dental anaesthesia simulation indicating that the hands-on session did not significantly improve students in theoretical knowledge (López-Cabrera et al., 2017), while another showed significant knowledge acquisition in the laboratory simulation group (Marei & Al-Jandan, 2013).

In the current study at T1, the groups based in TCD had a lower level of knowledge, and a significantly higher anxiety and stress level, than the equivalent groups from Brest. The reasons for baseline differences in knowledge are unclear and may be multifactorial. It can be speculated that due to different working habits, cultural differences, variations in the structure and organization of the academic curriculum, potentially different assessment methods at the end of the term, or the fact that all TCD students were in the second year, while some students were in the third year in BDU, that these variations were noted. Although baseline knowledge was lower in Dublin, there was a significant increase in knowledge from T1 to T2 in the experimental group, in contrast to Brest. Irish students appeared to consider the preclinical laboratory session to be more useful for knowledge acquisition.

Students who were generally anxious ($STAI-T \geq 47$), reported significantly greater anxiety ($STAI-S$) and stress, but less confidence at T1 with regard to the operative management of deep caries, as may be expected. Female students generally exhibited more anxiety and more stress

at T1 than male students, which concurs with previously reported gender differences (Dyrbye et al., 2006; Pau et al., 2007). It should be noted; however, that while general anxiety (STAI-T) and gender influenced the level of stress and anxiety at T1, they had no significant influence on the variation of the main parameters from T1 to T2, in the experimental group.

Finally, the overwhelming majority of the students were very satisfied with the preclinical laboratory training session. It was noted by the teachers that the teaching model may also be useful for general training in caries management, rather than just selective removal training, due to the lack of caries removal available in the preclinical laboratory sessions in both institutions. Despite instruction to the contrary, a cohort of the students proceeded to remove caries from the pulpal aspect of the cavity before removing superficial caries from the periphery of the cavity under the unsupported enamel. This approach led to inadvertent pulpal exposure in the selective removal aspect of the study and highlighted a lack of training in the manner in which to remove caries.

A limitation of this study is that the students were not blinded regarding the group they belonged to (as it was not possible to do so), which could influence their response to post intervention questionnaires and induce a reporting bias in the assessment of outcomes. Furthermore, the confidence questionnaire used was developed specifically for this study but was not previously validated before its use in the study. Another limitation of the study is that the opportunity to assess the development of clinical competency was not considered within this body of work. This was done principally due to lack of time in the curriculum, as the laboratory training would have to be repeated at least once and perhaps supplemented with another hands-on exercise with selective removal and pulpotomy. A second session would facilitate measurement of the progression of the experimental group between the first and the second training as well as a mechanism to compare the skills of the experimental group with those of the control group at the time of the second experimental group exercise. Another feature, which could in the future strengthen the training would be to record the session or to prepare a dedicated video and allow the students to watch the video for both techniques (selective removal and partial pulpotomy) in their own time. These videos could be shown not only during the lab, but also could be accessible to the students in their own time, a feature often requested by students in educational feedback on endodontic teaching (Chevalier et al., 2021; Inquimbert et al., 2019). The combination of a laboratory session and accompanying video was previously highlighted as an efficient way of improving students' didactic knowledge, clinical skills and confidence in medical education (Clark et al., 2014; Fradet

et al., 2020). Finally, the students did not routinely avail of magnification during the study, which is contrary to the recommendations for partial pulpotomy (ESE, 2019); however, it was considered that this was logistically too difficult to facilitate for all the participants many of which did not possess their own loupes.

CONCLUSION

The addition of a laboratory session using 3D-printed teeth that simulated deep caries and pulp exposure management, significantly reduced the stress and anxiety of students and also significantly increased their confidence. No significant improvement in theoretical knowledge could be demonstrated between the experimental and the control groups, despite a significant improvement of knowledge in the experimental group over the course of the study. Gender and anxiety STAI-Trait had no influence on the impact of this session, in terms of stress, anxiety, confidence or knowledge, while the university location had a significant influence on knowledge improvement. In both universities, students stated that they enjoyed the new laboratory session and they would like to benefit from other sessions employing this type of technology.

AUTHOR CONTRIBUTIONS

Valérie Chevalier, Marjolaine Dessert and Henry Fergus Duncan conceived and designed the study. Valérie Chevalier, Marjolaine Dessert, Kevin John Fouillen, Sile Lennon and Henry Fergus Duncan collected the data. Valérie Chevalier, Marjolaine Dessert and Henry Fergus Duncan performed the analysis. Valérie Chevalier and Henry Fergus Duncan wrote the article. Sile Lennon did the final proof reading.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICAL STATEMENT

Ethical approval was sought and approved for both centres in this study.

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REFERENCES

- Abuelniel, G.M., Duggal, M.S. & Kabel, N. (2020) A comparison of MTA and biodentine as medicaments for pulpotomy in traumatized anterior immature permanent teeth: a randomized clinical trial. *Dental Traumatology*, 36, 400–410.
- Al Raisi, H., Dummer, P.M.H. & Vianna, M.E. (2019) How is endodontics taught? A survey to evaluate undergraduate endodontic teaching in dental schools within the United Kingdom. *International Endodontic Journal*, 52, 1077–1085.
- American Association of Endodontists. (2021) *Position statement on vital pulp therapy*. Chicago, IL: American Association of Endodontists.
- Barros, M.M.A.F., De Queiroz Rodrigues, M.I., Muniz, F.W.M.G. & Rodrigues, L.K.A. (2020) Selective, stepwise, or nonselective removal of carious tissue: which technique offers lower risk for the treatment of dental caries in permanent teeth? A systematic review and meta-analysis. *Clinical Oral Investigations*, 24, 521–532.
- Bjørndal, L., Fransson, H., Bruun, G., Markvart, M., Kjældgaard, M., Näsman, P. et al. (2017) Randomized clinical trials on deep carious lesions: 5-year follow-up. *Journal of Dental Research*, 96, 747–753.
- Bjørndal, L., Simon, S., Tomson, P.L. & Duncan, H.F. (2019) Management of deep caries and the exposed pulp. *International Endodontic Journal*, 52, 949–973.
- Buerkle, B., Rueter, K., Hefler, L.A., Tempfer-Bentz, E.K. & Tempfer, C.B. (2013) Objective structured assessment of technical skills (OSATS) evaluation of theoretical versus hands-on training of vaginal breech delivery management: a randomized trial. *European Journal of Obstetrics & Gynecology and Reproductive Biology*, 171, 252–256.
- Careddu, R., Plotino, G., Cotti, E. & Duncan, H.F. (2021) The management of deep carious lesions and the exposed pulp amongst members of two European endodontic societies: a questionnaire-based study. *International Endodontic Journal*, 54, 366–376.
- Chevalier, V., Le Fur Bonnabesse, A. & Duncan, H.F. (2021) Frightened of the pulp? A qualitative analysis of undergraduate student confidence and stress during the management of deep caries and the exposed pulp. *International Endodontic Journal*, 54, 130–146.
- Chin, J.S., Thomas, M.B., Locke, M. & Dummer, P.M. (2016) A survey of dental practitioners in Wales to evaluate the management of deep carious lesions with vital pulp therapy in permanent teeth. *British Dental Journal*, 23, 331–338.
- Clark, N.P., Marks, J.G., Sandow, P.R., Seleski, C.E. & Logan, H.L. (2014) Comparative effectiveness of instructional methods: oral and pharyngeal cancer examination. *Journal of Dental Education*, 78, 622–629.
- Cooper, P.R. & Smith, A.J. (2016) Inflammatory processes in the dental pulp. In: Goldberg, M. (Ed.) *The dental pulp- biology, pathology and regeneration*. Heidelberg, Germany: Springer, pp. 97–112.
- Cooper, P.R., Takahashi, Y., Graham, L.W., Simon, S., Imazato, S. & Smith, A.J. (2010) Inflammation-regeneration interplay in the dentine-pulp complex. *Journal of Dentistry*, 38, 687–697.
- Cowpe, J., Plasschaert, A., Harzer, W., Vinkka-Puhakka, H. & Walmsley, A.D. (2010) Profile and competences for the graduating European dentist – update 2009. *European Journal of Dental Education*, 14, 193–202.
- De Moor, R., Hulsmann, M., Kirkevang, L.L., Tanalp, J. & Whitworth, J. (2013) Undergraduate curriculum guidelines for Endodontology. *International Endodontic Journal*, 46, 1105–1114.
- Dyrbye, L.N., Thomas, M.R. & Shanafelt, T.D. (2006) Systematic review of depression, anxiety, and other indicators of psychological distress among U.S. and Canadian medical students. *Academic Medicine*, 81, 354–373.
- Edwards, D., Bailey, O., Stone, S. & Duncan, H. (2021) The management of deep caries in UK primary care: a nationwide questionnaire-based study. *International Endodontic Journal*, 54, 1804–1818.
- Emara, R., Krois, J. & Schwendicke, F. (2020) Maintaining pulpal vitality: cost-effectiveness analysis on carious tissue removal and direct pulp capping. *Journal of Dentistry*, 96, 103330.
- ESE. (2019) European Society of Endodontology position statement: management of deep caries and the exposed pulp. *International Endodontic Journal*, 52, 923–934.
- Field, J.C., Cowpe, J.G. & Walmsley, A.D. (2017) The graduating European dentist: a new undergraduate curriculum framework. *European Journal of Dental Education*, 21(Suppl. 1), 2–10.
- Field, J.C., Kavadella, A., Szep, S., Davies, J.R., DeLap, E. & Manzanares Cespedes, M.C. (2017) The graduating European dentist—domain III: patient-centred care. *European Journal of Dental Education*, 21(Suppl. 1), 18–24.
- Fontana, M., Guzmán-Armstrong, S., Schenkel, A.B., Allen, K.L., Featherstone, J., Goolsby, S. et al. (2016) Development of a core curriculum framework in cariology for U.S. dental schools. *Journal of Dental Education*, 80, 705–720.
- Fradet, L., Iorio-Morin, C., Tissot-Therrien, M., Fortier, P.H. & Colas, M.J. (2020) Training anaesthetists in cricothyrotomy techniques using video demonstrations and a hands-on practice session: a shift towards preferred surgical approaches. *British Journal of Anaesthesia*, 125, e160–e162.
- GBD 2017 Oral Disorders Collaborators, Bernabe, E., Marcenes, W., Hernandez, C.R., Bailey, J., Abreu, L.G. et al. (2020) Global, regional, and national levels and trends in burden of oral conditions from 1990 to 2017: a systematic analysis for the global burden of disease 2017 study. *Journal of Dental Research*, 99, 362–373.
- Hattar, S., AlHadidi, A., Altarawneh, S., Hamdan, A.A.S., Shaini, F.J. & Wahab, F.K. (2021) Dental students' experience and perceived confidence level in different restorative procedures. *European Journal of Dental Education*, 25, 207–214.
- Haug, S.R., Linde, B.R., Christensen, H.Q., Vilhjalmsen, V.H. & Bårdsen, A. (2021) An investigation into security, self-confidence and gender differences related to undergraduate education in endodontics. *International Endodontic Journal*, 54, 802–811.

- Hesson, M. & Shad, K.F. (2007) A student-centered learning model. *American Journal of Applied Sciences*, 4, 628–636.
- Innes, N.P., Frencken, J.E., Bjørndal, L., Maltz, M., Manton, D.J., Ricketts, D. et al. (2016) Managing carious lesions: consensus recommendations on terminology. *Advances in Dental Research*, 28, 49–57.
- Inquimbert, C., Tramini, P., Romieu, O. & Giraudeau, N. (2019) Pedagogical evaluation of digital technology to enhance dental student learning. *European Journal of Dentistry*, 13, 53–57.
- Lesage, F.X. & Berjot, S. (2011) Validity of occupational stress assessment using a visual analogue scale. *Occupational Medicine*, 61, 434–436.
- Lesage, F.X., Berjot, S. & Deschamps, F. (2012) Clinical stress assessment using a visual analogue scale. *Occupational Medicine*, 62, 600–605.
- Liu, X., Liu, M., Yang, Y., Fan, C. & Tan, J. (2019) Step-by-step teaching method improves the learner achievement in dental skill training. *European Journal of Dental Education*, 23, 344–348.
- López-Cabrera, C., Hernández-Rivas, E.J., Komabayashi, T., Galindo-Reyes, E.L., Tallabs-López, D. & Cerda-Cristerna, B.I. (2017) Positive influence of a dental anaesthesia simulation model on the perception of learning by Mexican dental students. *European Journal of Dental Education*, 21, e142–e147.
- Marei, H.F. & Al-Jandan, B.A. (2013) Simulation-based local anaesthesia teaching enhances learning outcomes. *European Journal of Dental Education*, 17, e44–e48.
- Marty, M., Broutin, A., Vergnes, J.N. & Vaysse, F. (2019) Comparison of student's perceptions between 3D printed models versus series models in paediatric dentistry hands-on session. *European Journal of Dental Education*, 23, 68–72.
- McDowell, I. (2006) *Measuring health: a guide to rating scales and questionnaires*. New York, NY: Oxford University Press.
- Mjör, I.A. & Tronstad, L. (1974) The healing of experimentally induced pulpitis. *Oral Surgery, Oral Medicine, and Oral Pathology*, 38, 115–121.
- Nascimento, M.M., Behar-Horenstein, L.S., Feng, X., Guzmán-Armstrong, S. & Fontana, M. (2017) Exploring how U.S. dental schools teach removal of carious tissues during cavity preparations. *Journal of Dental Education*, 81, 5–13.
- Pau, A., Rowland, M.L., Naidoo, S., AbdulKadir, R., Makrynika, E., Moraru, R. et al. (2007) Emotional intelligence and perceived stress in dental undergraduates: a multinational survey. *Journal of Dental Education*, 71, 197–204.
- Perry, S., Bridges, S.M. & Burrow, M.F. (2015) A review of the use of simulation in dental education. *Simulation in Healthcare*, 10, 31–37.
- Qualtrough, A.J. (2014) Undergraduate endodontic education: what are the challenges? *British Dental Journal*, 216, 361–364.
- Rajan, S., Chen, H.Y., Chen, J.J., Chin-You, S., Chee, S., Chrun, R. et al. (2020) Final year dental students' self-assessed confidence in general dentistry. *European Journal of Dental Education*, 24, 233–242.
- Reymus, M., Fotiadou, C., Kessler, A., Heck, K., Hickel, R. & Diegritz, C. (2019) 3D printed replicas for endodontic education. *International Endodontic Journal*, 52, 123–130.
- Schwendicke, F., Frencken, J.E., Bjørndal, L., Maltz, M., Manton, D.J., Ricketts, D. et al. (2016) Managing carious lesions: consensus recommendations on carious tissue removal. *Advances in Dental Research*, 28, 58–67.
- Segura-Egea, J.J., Zarza-Rebollo, A., Jiménez-Sánchez, M.C., Cabanillas-Balsera, D., Areal-Quecuty, V. & Martín-González, J. (2021) Evaluation of undergraduate endodontic teaching in dental schools within Spain. *International Endodontic Journal*, 54, 454–463.
- Shams, L. & Seitz, A.R. (2008) Benefits of multisensory learning. *Trends in Cognitive Sciences*, 12, 411–417.
- Spielberger, C.D. (1983) *Manual for the state-trait inventory STAI (form Y)*. Palo Alto, CA: Mind Garden.
- Spielberger, C.D. (1989) *State-trait anxiety inventory: bibliography*, 2nd edition. Palo Alto, CA: Consulting Psychologists Press.
- Tikhonova, S., Girard, F. & Fontana, M. (2018) Cariology education in Canadian dental schools: where are we? Where do we need to go? *Journal of Dental Education*, 82, 39–46.
- Widbillier, M., Ducke, S., Eidt, A., Buchalla, W. & Galler, K.M. (2018) A training model for revitalization procedures. *International Endodontic Journal*, 51(Suppl 4), e301–e308.
- Yuan, J.X., Yang, K.Y., Ma, J., Wang, Z.Z., Guo, Q.Y. & Liu, F. (2020) Step-by-step teaching method: improving learning outcomes of undergraduate dental students in layering techniques for direct composite resin restorations. *BMC Medical Education*, 20, 300.

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