Investigating the validity of a novel paediatric pulpotomy scoring system across typodont and digital 3D preparations

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The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others.

Dedicated to my family

“There are no shortcuts to any place worth going.”

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Abstract

Dental education has benefited to a great extent from technology in both teaching and learning fields. Implementation of technology has paved a new way for creative teaching methods and student assessments. Preclinical assessment of dental students can be affected by various factors. These factors include the type and design of assessment used and assessor calibration. Traditional visual assessment relies on the assessor's experience to evaluate the student's preparation. Computer software assessment produces consistent scores for the student's assessment but suffers from the inability to assess all the relevant criteria for the dental procedure.

Aims: The study aimed to develop and validate a standardised scoring system for a routine paediatric dental procedure (pulpotomy) on a typodont tooth mounted in a phantom head simulator to be used by staff teaching dental students, and to investigate the participants' scoring consistency in assessing the prepared typodont tooth directly and a scanned 3D image of the same preparation.

Methods: The research design consists of two studies. The preliminary study: a questionnaire was designed and circulated to the participants to identify the need for further training on routine paediatric dental procedures and evaluate the confidence level of the participants on carrying out routine paediatric dental procedures. The main study: the principal researcher carried out the chosen dental procedure (pulpotomy) identified in the preliminary study on five typodont teeth. The typodont teeth with their preparations were scanned with an intra-oral scanner and saved as 3D

images. A scoring system was designed and circulated to the participants (teachers of undergraduate students in paediatric dentistry) to assess the typodont teeth and the 3D images. The study consisted of 26 participants of consultants, specialists, and postgraduate students teaching paediatric dentistry. Two participants were selected to repeat the assessment to evaluate intra-assessor reliability. The participants assessed five typodont teeth and 3D images of the same teeth on two separate days to prevent any bias.

Results: Fleiss' Kappa statistical analysis was used to determine the reliability of the participant assessment scores. The results showed a fair level of agreement of the typodont and the 3D image assessment scores. A mixed model analysis was used to assess the agreement level between the typodont and 3D image assessment. The results showed no significant difference between the typodont teeth and the 3D image assessment scores. Fleiss' Kappa analysis was used to assess the intra-participant reliability of the assessment scores. The agreement was high for both methods but tended to be higher for the traditional assessment method.

Conclusion: The study results showed no statistically significant difference between the assessment scores of the typodont teeth and the 3D images. The assessment of 3D images of typodont teeth preparations can be a valid assessment method that can benefit dental students' education. The results showed high intra-participants reliability in the assessment scores.

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Chapter 1 Introduction

The different educational processes can be considered as a cycle. The cycle starts with setting education aims and objectives. Then, the cycle continues with a period of instructional practice where the students aim to achieve the goals before moving into a period of assessment and evaluation of the students' progress. There are two types of assessment divided into formative and summative assessments. Formative assessments consist of feedback that aids students' performance. On the other hand, summative assessment is usually used at the end of the educational process and assesses if the students achieved the aims and objectives of the education process (Schartel, 2012). Dental schools around the world are faced with a challenge to develop a suitable and reliable assessment system for the dental student's preclinical education (Tennant and Scriva, 2000). Feedback is an important part of the assessments process and the learning cycle of dental students. Inconsistent feedback by the teachers can have a negative effect on students learning and development of dental skills (Henzi et al., 2007). Effective feedback should be consistent, specific, and delivered in a timely manner to aid the student's education. Consistent feedback with a reliable assessment system might benefit the dental students learning and aid in the assessment of the dental students.

1.1 Education

The How People Learn (HPL) is a framework by Bransford and Schwartz (1999). The framework aims to facilitate creating a learning environment where all the factors that influence how people (students) learn are present and balanced for learning. Various factors affect students' learning, such as

background knowledge and interests, along with internal motivation. Also, students should be provided with the freedom to learn (Bransford and Schwartz, 1999). Evidence has indicated that cycling between shadowing a clinician in a dental clinic and practice in dental education will enhance manual dexterity skills development and retention. Yet, these methods are believed to be underused in dental education (Horst et al., 2009). Most dental schools around the world have produced instructional videos as a learning method for students showing waxing up teeth and cutting cavity preparations. These methods, although they are helpful, have shortcomings. These shortcomings include the lack of human interaction, treatment planning, and patient management. On the other hand, incorporating virtual reality (VR) technology into preclinical teaching will increase the chances for dental skill acquisition, feedback, and observing, as it's reported in the literature that students carry out more dental procedures on the haptic simulator when compared to the traditional simulator (Horst et al., 2009). Understanding the factors that affect how students learn could aid in the assessments process in the preclinical stage of dental students. There are four stages of the learning cycle that could influence how students learn. Kolb (1975) experimental learning cycle presents effective learning for the students. The cycle consists of 1- concrete experience 2- reflection observation 3- analysis and conclusions 4- plan and try out what you have learned.

1.2 Feedback

Feedback is an essential element used to help the students learn and improve in preclinical dentistry. Feedback is defined by Hattie and Timperley

(2007) as “information provided by an agent (e.g., teacher, peer, book, parent, self, experience) regarding aspects of one’s performance or understanding”. In order to guide novice dental students into competence, effective dental skill assessment is needed. Assessments do give teachers insight into the student’s improvements. But students only really benefit from the feedback resulting from the assessment.

Dental students rely on the teacher’s feedback to improve their skills (Hauser and Bowen, 2009). Assessment of dental students’ performance in preclinic learning can be considered with written or oral feedback. Feedback aids the students to gain and develop manual dexterity skills when used with the traditional and haptics simulators. Feedback should be used in a timely manner to benefit the students, and it should be instant and frequent so it can improve student learning (Roy et al., 2017). Different types of feedback complement the assessment of dental students in the preclinical training. Oral feedback can be an influential and powerful method in improving the student’s performance when used in a timely manner. Written feedback is often delivered to the students after completing a certain task. It is considered an effective method of feedback as the students keep a record of feedback to reflect on and improve their performance (Hattie and Timperley, 2007). Essential to effective learning in simulation training is the role of feedback on a student’s performance. Dental students in their 1st year of study are considered novice learners of the stages of competence. Beginner students are dental students with basic dental skills in their 2nd or 3rd year of their studies. The novice students depend on teachers’ instruction to improve their motor skills and require immediate and accurate feedback (Chambers and Glassman, 1997). Novice and beginner students depend on

feedback for improvements, as they are incapable of evaluating their performance. This is supported by Chambers (2012) findings that novice students require more time to complete class II cavity preparations, as they took more time to complete the preparations than beginner students. Well-timed and specific feedback about the students' performance is essential in aiding the students to achieve new skills. In a study carried out by Stewart et al. (2010) the students recognized feedback as an essential part of the learning process. Also, the students reported that they were not satisfied with the feedback level received. The manner of feedback delivery to dental students is important to students' ability to learn efficiently. Also, undergraduate students don't have the necessary experience to link the information to experience. Computerized simulators provide continuous feedback during and after completing the dental procedure. Students request more evaluation and feedback while using a haptic simulator than the traditional simulator. This might indicate that students view frequent feedback as a helpful method of learning. Also, it is reported in the literature that manual dexterity skills acquisition was accelerated when device and instructor feedback was given simultaneously with the manual dexterity exercise (Perry et al., 2015; Al-Saud et al., 2017). A survey by Henzi et al. (2007) found that dental students feel the learning process is affected negatively by inconsistent feedback. To conclude, feedback is a valuable part of a student's education. Consistent and timely feedback is beneficial for the students learning and assessment in the preclinical phase. Oral and written feedback is a valued tool in preclinical learning and complements the assessment of the student's performance.

1.3 Dental Education

Dental education has benefited to a great extent from technology in the teaching field. Implementation of technology has paved a new way for innovative teaching methods and increased student engagement (Dragan et al., 2018). Traditional educational methods that have been used by Schools of Dentistry across the world include typodont (plastic) teeth or natural extracted teeth mounted in a traditional phantom head simulator. These methods have long been the standard for preclinical teaching methods in dental education. The traditional phantom head simulator is advantageous in simulating the oral cavity and allows the use of typodont (plastic) teeth for practice dental procedures (Perry et al., 2015). Assessment of dental students is a valuable part of preclinical dental education. The methods of assessment consist of traditional visual assessment or digital assessment methods. Digital assessment methods consist of computer software that assesses the student's preparation against unprepared teeth (Park et al., 2017).

There is a lack of information on paediatric dentistry teaching and assessments in the UK dental schools (Grindrod et al., 2020). A study by Grindrod et al. (2020) reported a wide range of assessment methods being used to evaluate dental student competencies in UK universities. These methods include competencies, logbooks, clinical totals, and paediatric case presentations. In the study, there was no mention of the assessment criteria for preclinical training with phantom head simulators in dental schools. Several studies calculated the numbers and types of paediatric dental procedures carried out by undergraduate dental students. But none of the studies reported scoring the student procedures with a scoring system

designed for paediatric dental procedures. A study by Stewart et al. (2010) looked at the logbooks for 4th year dental students retrospectively over their 4th and 5th year and paediatric dentistry training. The study reported that the dental students had limited experience in paediatric pulp treatments (pulpotomy). The study had a limited sample size of 30 participants, which might not represent the dental school. This presents the need for further training, and assessments designed with paediatric dental procedures in mind could be beneficial.

The most common simulators used in preclinical dental training are the traditional phantom head simulator and the dental haptic simulator. A 3D version of a tooth preparation can be prepared in one of two ways. Firstly, a prepared typodont tooth can be 3D scanned with an intraoral scanner. Secondly, the virtual tooth can be prepared directly using a haptic simulator.

Although dental haptic simulators are considered a valued educational tool that could supplement the current traditional teaching methods, there is a lack of validated scoring systems for an overall dental procedure. But there are some specific aspects of a procedure for example, caries removal during cavity preparation can be validly automatically scored on a dental haptic system (Osnes et al., 2020). The development of scoring systems could help assess student performance more reliably and help assess different available simulators and their benefits in the preclinical stage of dental training. In order to maximize the educational value of simulator learning, further investigation is needed into the importance of tutor feedback and simulator-based feedback and the effect of using a validated scoring system on the student preclinical learning process.

Current literature states that traditional phantom head simulators are the main educational tool in dental students' preclinical training (Perry et al., 2015). Studies on the traditional simulator focused on skill acquisition and retention and assessment of dental students on routine dental procedures such as caries removal, cavity preparation, and crown preparation. The dental education literature in the past years has focused on the dental schools' undergraduate curriculum and the methods of learning and assessment. Also, the literature discusses the need for a validated scoring system to complement preclinical training.

1.4 Technology-based learning

Technology-based learning has played a significant role in the past 50 years in high-risk education fields (Al-Taweel et al., 2021). It provides preclinical training for irreversible and reversible procedures for medical and dental students to practice safe and effective treatment for high-risk procedures. Technology-based learning can be defined as a learning method that depends on the integration of information technologies, digitizes content, or digitizes web-based interaction to better suit the learning method of the students (Al-Taweel et al., 2021). It provides novel ways for medical and dental students, trainees, and academic staff to obtain advanced training and maintain the necessary clinical abilities for safe and effective practice. In the past 50 years, simulation-based training has been used in medical and dental training and has played a major role in the education process (Buchanan, 2001).

Technology-based learning should be used in the learning process when there is a clear benefit to patient care. A safer method for patient care can

be offered by simulation devices, which can be integrated into the health service for preclinical training. Healthcare professionals should learn skills in a simulation environment before practicing in a supervised clinical setting (Curran, 2011).

The Department of Health for England has developed a framework of six principles concerning Technology Enhanced Learning (TEL). These principles aim to improve patient care, enhance the learning process, and train staff with the required skills for safe and effective patient care (Curran, 2011).

Principles of Technology Enhanced Learning (Curran, 2011):

• *Be patient-centred and service-driven – technological applications must focus on equipping the workforce with the necessary skills for safe and effective patient care.*

• *Be educationally coherent – any technological application should address clearly articulated learning needs that are aligned to service needs.*

• *Be innovative and evidence-based – applications should enhance training, be informed by the best available evidence, and, where possible, be future-proof by being flexible and adaptive so minimizing redundancy.*

• *Deliver high-quality educational outcomes – meets and, wherever possible, exceeds agreed standards.*

• *Deliver value for money – technological applications should enhance training, improve productivity, reduce duplication and be affordable and cost effective.*

• *Ensure equity of access and quality of provision – applies across the health and social care workforce.*

Technology based learning in preclinical simulators provides safe and effective methods for dental students to practice different types of

procedures. Also, the students can use the dental haptic simulators out of hours without the need for tutor supervision. Although the haptic simulator is expensive, it’s an effective method of practice in high-risk and irreversible procedures (Buchanan, 2001). Also, it eliminates the need for dental handpiece and dental burs, which is used in traditional simulators. Finally, the Haptic dental simulators can’t replace the traditional phantom head for dental students' preclinical learning but can complement the phantom head simulator in preclinical training (Buchanan, 2001).

The newer teaching methods of dental haptic simulators provide feedback to dental students in a 3D virtual environment, with no physical teeth used. Currently, there are no studies that investigate the efficiency of assessing a 3D image rather than a typodont tooth preparation. The current study seeks to explore this, which might lead to the benefit of haptic education and digitize typodont education.

1.5 The Assessment of Dental Students

Gaining fine motor skills is vital for dental students to perform a routine dental procedure. The use of an effective evaluation system aids in assessing and improving the dental students’ learning process (Hauser and Bowen, 2009). In dentistry, dental students are assessed in various ways, including written exams, oral exams, and Objectively Structured Clinical Examination (OSCE). The most common assessment method for the dental student is to prepare a plastic tooth mounted on a traditional phantom head simulator either in OSCE format or in a laboratory setting (Williams et al., 2015). The assessment system should be designed with a clear and specific criterion that details the procedure and the students’ performance.

Assessments should be brief and accurate. Immediate feedback should be used with the assessment of the dental student (Knight, 1997). The assessment of students has been described in the literature as a systematic determination of student performance and achievement (Williams et al., 2015). Preparing dental students to deliver treatment on actual patients requires assessments against a series of standards. In order to identify the student's strengths and weaknesses, a proper assessment tool should be chosen (Schuwirth and Van der Vleuten, 2011; Williams et al., 2015). Preclinical assessment of dental student preparations is a fundamental part of dental education, and it should be designed to evaluate the students' knowledge and skills. Also, it should deliver feedback and follow the progress of the students over the course of their studies. Reliability and validity are vital characteristics of a good assessment method. The assessment should measure what it intends to measure and produce the same results when repeated to be considered valid and reliable. Assessment by an individual evaluator suffers from inter-examiner and intra-examiner variability (Taylor et al., 2013). A review of the literature by Albino et al. (2008) found five main methods of dental student assessment. The five methods are laboratory-based exams, multiple-choice question exams, completing a required number of procedures, daily gradings, and competency assessments during patient care. The literature has multiple examples of the development and validation of assessments systems. An essential feature of these systems is implementing clear and meaningful assessment criteria (Hauser and Bowen, 2009). Knight (1997) reported that the assessment system should be valid and reliable. Also, the marking criteria must define each performance score so that each student's

performance can be clearly outlined and scored. Knight (1997) revised the marking system and included a specific marking category, these categories included excellent, clinically acceptable, and criterion not met. The aim of using only three categories is improved the interrater and intrarater agreement and to enhance the training of the students by providing accurate assessment scores.

1.5.1 Practical Test in Simulated Clinical Settings or Laboratory Settings:

The dental student carries out a defined practical procedure on typodont (plastic) teeth mounted on a phantom head simulator in a simulated setting. Depending on the dental procedure (Cavity preparation or dental crown preparation), the assessment might occur at each stage or at the end of the procedure for the final result of the assessment. Marking is carried out by an expert in the field by a checklist assessment with a mark of a pass or fail. Other assessment systems use a universal assessment system consisting of ideal, satisfactory, borderline, or unsatisfactory. The literature lacks any assessment criteria for evaluating routine paediatric dental procedures (Williams et al., 2015).

1.5.2 Checklist Assessment vs. Two-point system

The two-point system consists of either pass and fail or correct and incorrect grades. The checklist system consists of detailed descriptions of each criteria. A study by Houpt and Kress (1971) aimed to evaluate the reliability and accuracy of the different assessment systems in dental cavity preparation. The study used three different scales for the assessments. The 1st scale consisted of two points (correct and incorrect) with scores of one and zero, the 2nd scale scores from zero to four, and the 3rd scale consisted

of scores from zero to four with descriptors for each score. The participants consisted of 36 dentists, 30 junior dentists, and 16 student dental assistants. The authors justified the different sample sizes due to the unavailability of the students at the time of the study. However, the study used dental assistants as a way to include different dental experience levels. The study was well designed as the participants were divided into three groups. Each group consisted of different levels of dentists and dental assistants, with five expert evaluators used. Although the two-point scale had the best agreement, the study mentioned that the five-point scale with descriptions is more suitable for teaching. It provided feedback and explanation for each score given to the participants (Houpt and Kress, 1971).

The checklist assessment with descriptors results may vary compared to a 2-point scale, but it provides better feedback for dental students. Another benefit of checklist assessment is enhancing inter-examiner reliability, supported by Goepferd and Kerber (1980) study. A checklist assessment system was developed and used by Goepferd and Kerber (1980) to evaluate class II cavity preparations in primary teeth. The marking system was compared to traditional visual assessment (glance and grade) evaluation. Glance and grade assessments are traditional visual assessment method used to evaluate students' preparations visually. Fifteen examiners with different levels of experience evaluated 24 class II cavity preparations. The study found that the checklist assessment system enhanced inter-examiner reliability. A published guide by Licari et al. (2008) for the development of a marking system for preclinical and clinical student's performance pointed out the importance of clearly defining the assessment criteria and the organization of the assessment form. Consistent and standard terminology

for the assessment form is important for both students and teachers. A clear definition of the marking criteria was used in this study, defining each criteria with a relevant score. The two-point (pass-fail) assessment only provides results on the students' performance. As for the checklist, the assessment provides a grade and a justification of the grade given to the dental student's performance (Hauser and Bowen, 2009). Learning new manual skills in dentistry is not easy, especially with dental students performing under stress and anxiety, making it more difficult to learn. The literature reported assessments systems had positive effects on students by reducing stress, especially when the student understands the dental procedure and the criteria of the assessment system (Hauser and Bowen, 2009). A study by Sharaf et al. (2007) compared a checklist assessment with a traditional visual (glance and grade) marking system to evaluate cavity preparations on typodont teeth. The study used primary (paediatric) plastic teeth and recruited 3rd year dental students. The students performed a wide range of cavity preparations in this study. The procedures included two Class I, II, and III cavity preparations and one class V preparation. The study might be criticized because there was not any mention of the calibration and training for the examiners, which consisted of three specialists in paediatric dentistry. The study found minimal intra-examiner variability. On the other hand, the study found a significant inter-examiner variability with both marking systems used.

The intra-examiner variability is less of an issue when assessing dental students, as its more likely to have more intra-examiner agreement than inter-examiner agreement. As for the inter-examiner variability, it can be minimized with the use of a small point scale for the assessment with

checklist criteria (Sharaf et al., 2007). The traditional visual assessment can be open to interpretation by the assessors, which might lead to the variability of the assessment scores. Also, examiner calibration is important in achieving minimal variability in the assessment scores.

Students will always request feedback from the teacher on their performance, so it is essential that feedback and assessment are accurate and help students improve. The factors affecting students' assessments include the type of rating scale used, the suitability of the criteria, and the rater (teacher) calibration (Haj-Ali and Feil, 2006).

1.5.3 Assessors Reliability and Calibration

Calibration of teachers is valuable for novice students' assessment and development of their dental skills. The students may benefit from the accurate assessment scores that reflect on their performance. One factor that has the potential to influence the reliability of the clinical assessment is the inter-examiner variability. Using multiple trained and calibrated examiners is a way to minimize this drawback in evaluating dental students (Hauser and Bowen, 2009; Williams et al., 2015). Various factors contribute to the disagreement of student evaluation, such as the type and the method of assessment. To overcome the inconsistent results, the assessment system should be designed for the preclinical and clinical assessment with validated criteria, a proper rating scale, and a calibration of the teachers. A study by Jenkins et al. (1998) aimed to assess the inter-examiner and intra-examiner variability of clinical staff assessment of the dental student's preparation by using the traditional visual marking system. The study had a large sample size of 75 typodont teeth, randomly coded into the study for

assessment. The authors didn't intend to carry out calibration or training for the examiners in the study because the aim of the study was to assess variability in not-calibrated examiner, and to produce a baseline score of the assessment method used to evaluate the dental student's preparations. The results reported inconsistency in staff assessment of dental student preparations with a high level of inter-examiner and intra-examiner variability. The study recommended the use of a more comprehensive assessment method to assess the preparations. Also, better staff training and calibration with a detailed checklist will help in the preclinical assessment of dental students (Jenkins et al., 1998). Issues with assessment subjectivity have been reported across different academic specialties. Various studies reported marked inter-examiner variability while assessing the operative skills of dental students, while intra-examiner variability seemed to be less commonly found (Sharaf et al., 2007). The reasons for the variability of student assessment include the hesitancy to give a good score for preparation if it has been carried by a student (Taylor et al., 2013). Also, a rating scale without a guide or criteria might be open to interpretation by an assessor. As a result, the use of a guide for the marking assessment has been advocated in the literature (Taylor et al., 2013). The literature states that calibration of the assessors (teachers) is more successful when the rating scales are limited to a small scale (Haj-Ali and Feil, 2006). It would therefore seem from the literature that an assessment system using a small number of rating categories is an effective method of assessing dental students' preparations. Assessor calibration and using a suitable assessment method might benefit students' education and produce an accurate assessment of their performance.

1.6 Reliability and validity

In quantitative research, consideration should be made to the reliability and validity of research methods and measurements. Validity refers to the accuracy of a method in its measurement of what it is intended to measure. Ensuring validity refers to whether an accurate conclusion can be obtained. If a method measure what it intended to measure, and the results are reproducible, then it can be considered valid. There are five main types of validity (Peter et al., 2017):

1.6.1 Construct validity

Construct validity assesses the relation of a measure to existing theory and knowledge of the concept being measured. It also evaluates whether a measurement method represents the object intended to measure. It's central to establishing the overall validity of a method (Peter et al., 2017).

1.6.2 Content validity

Content validity assesses whether a test is representative and covers all aspects of the concept being measured. All relevant parts of the subject must be covered by the measurement method (test) to produce valid results. If some aspects are missing from the measurement method or the inclusion of irrelevant aspects, the validity will be threatened (Peter et al., 2017).

1.6.3 Criterion validity

It assesses the extent to which the result of a measure corresponds to other valid measures of the same concept. Also, criterion validity evaluates how closely the results of your test correspond with the results of a different test. Suppose there is a high correlation between the results of your

measurement and the results of the criterion measurement. In that case, it demonstrates a good indication that your test is measuring what it intends to measure (Peter et al., 2017).

1.6.4 Face validity

Face validity considers the suitability of the test components and how it seems to be on the surface. It has similarities to content validity, but face validity is regarded as a more informal and subjective assessment. Although face validity can be helpful in the initial stages of developing a method, it’s often considered the weakest form of validity due to the subjective measurement method (Peter et al., 2017).

1.6.5 Consequential validity

Consequential validity refers to the assessment impact that might occur on the student's behaviour.

A newly developed assessment system evaluating a dental student in the preclinical phase should be validated prior to applying it to actual students. A valid assessment system allows for an accurate evaluation of the student’s performance. Also, an assessment system's results should be reproducible and cover all aspects of the procedure evaluated (Peter et al., 2017).

1.7 Education approaches for clinical Dentistry

Different types of simulators are used for preclinical training for dental students. The traditional phantom head simulator is considered the gold standard for the training of dental procedures in the preclinical phase for dental students. Recently, dental schools have used dental haptic simulators

and computer-assisted software for training and assessing dental students' performance (Buchanan, 2001).

1.7.1 Traditional phantom head dental simulator

The use of simulation in the dentistry field is vital due to the high risks and the irreversible nature of most clinical procedures. The dental students must have the necessary skills for safe practice at the time of patient treatment. The phantom head simulator is considered an essential teaching method for dental students' preclinical training (Perry et al., 2015). Modern phantom head simulators replicate natural teeth by using artificial teeth and include many features to duplicate the oral cavity to increase fidelity. However, the opportunity for students to practice on natural extracted teeth is not applicable with the traditional phantom head simulator. Typodont (plastic) teeth are used, which may provide an adequate learning experience for dental students (Perry et al., 2015). Also, the clinical staff can provide feedback and evaluation during the training exercises. In addition, the cost of disposable equipment such as plastic teeth and burs might limit the amount of practice. Also, the literature reports that some degree of repetitive practice with the traditional phantom head simulator is an essential component of motor skill learning (Fugill, 2013; Perry et al., 2015).

The use of traditional phantom head training to develop dental skills has been in use since the early 1900s and is present nowadays in its updated form. Since its introduction in dental schools worldwide, the phantom head simulator has maximized teaching efficiency and minimized the risk of infection and injury in preclinical dental education. These simulators offer benefits to novice dental students in the form of using the dental handpiece

and the dental mirror. Also, it allows the development of finger rest which provides stability and accuracy while performing routine dental procedures like cavity preparation, which is an essential part of a skill set that the student must acquire before gaining any more complex skills (Perry et al., 2015). The traditional phantom head simulator is the standard learning method for preclinical training for dental students. Another requirement for the phantom head exercises is the need for faculty members to supervise the students while the students are practicing on the dental simulator due to using dental handpieces with real dental bur (Perry et al., 2015).

1.7.2 Computer-Assisted Simulation and Assessments

In 2000 computer-assisted simulation was introduced, which is considered a new method for motor skill learning that led to creating a new approach for motor skill learning in dental education. Computer software creates a virtual reality environment and allows users to interact and navigate the virtual world like real life (Ender et al., 2019). Initially, the CAD/CAM technology was developed for manufacturing and designing fixed prosthetics in the dental clinic. Recently, the use of CAD/CAM has been used in dental education (Ender et al., 2019).

The dental education field has explored methods to enhance student preclinical assessments. Some manufacturers have developed digital preparation assessment tools. These originally started as a chairside guide for the operator, like identifying undercuts in a crown preparation, and have latterly become attempts at stand-alone assessment software, which tries to assess a student crown preparation (prepCheck) (Park et al., 2017). The use

of novel technologies can improve dental education and help dental student assessment in the preclinical phase by applying a reliable technique. The literature reported that the CAD/CAM software can produce a high level of precision when assessing dental preparations (Callan et al., 2014). Introducing these technologies in preclinical education is advantageous to dental students' learning by providing immediate feedback and assessment. Also, it can reduce some of the need for academic staff supervision in the preclinical learning stage. Various types of digital technologies and computer software have been developed to help educate and assess dental students in the preclinical phase. These technologies include Computer-assisted Learning (CAL), Computer-assisted Simulation (CAS), and Computer-aided Instruction (CAI). The advantage of these systems is that they are easy to access by students and allow them to learn at their own pace. Commercial examples include DentSim (DenX Ltd, Jerusalem, Israel), Kavo PrepAssistant (Kavo, Biberach, Germany), E4D Compare (D4D Technologies, Richardson, TX, USA), and prepCheck (CEREC Sirona, Bensheim, Germany) (Gratton et al., 2017). In Hamil et al. (2014) study, dental students and academic staff showed overall positive attitudes toward the use of digital assessment software as a tool for objective evaluation and scoring student preparations in preclinical dental education (Hamil et al., 2014).

1.7.2.1 Dentsim

One of the first digital systems commercially available to dental schools was DentSim (DenX Ltd, Jerusalem, Israel), which allows for a wide variety of dental procedures to be performed. DentSim is a system that can be

combined with traditional phantom head simulators. The software offers the dental students simulated patient information, feedback, and evaluation of the student preparations. The DentSim software can save preparations which can be viewed again by students and supervisors. One of the main advantages is its ability to evaluate student's work against an ideal standard. Also, notification of error is provided to the student immediately, which aids in enhancing their motor skill learning and retention. It also provides the students with a detailed evaluation. The other advantage of the software is that the dental students use the traditional phantom head, which is an essential learning tool for preclinical education (Taylor et al., 2013; Perry et al., 2015). Furthermore, it is reported in the literature that the acquisition of manual dexterity skills was accelerated when device and instructor feedback was given simultaneously in the exercise (Al-Saud et al., 2017). The efficiency of the learning experience was more elevated when DentSim was used as the dental students could prepare twice as many haptic preparations per hour compared to what they achieved with traditional simulation due to automatic feedback received from haptic simulators (Buchanan, 2001).

In addition, students on the DentSim can take advantage of the ease of evaluation by requesting evaluations up to three times more often than in the traditional preclinical laboratory setting. The evaluation is standardised, leaving no room for bias or errors. Also, students can perform the following treatment steps without having to wait for the instructor's approval. The DentSim detects when a student's performance is below standard and stores visual records for review. The limitation of DentSim is that the final assessment has to be carried out by a member of staff with the device

providing objective tracking of the student's preparations (Perry et al., 2015, Xia et al., 2013, Buchanan, 2001). Jasinevicius et al. (2004) carried out a study aimed to compare the use of DentSim with a traditional phantom head for dental students. They found that students completed their preparations in less time when trained with DentSim and needed less staff supervision. The study found no significant differences in awarded grades between the two groups, though the students who used the traditional phantom head did get slightly higher grades. The study had a relatively small sample size of 28 participants of 1st year dental students with no experience in cavity preparations. The study was well designed as the distribution of each group was based on their grade at a laboratory exercise. Then the students were assigned randomly to either VR or traditional groups. The study used a marking system consisting of 4 grades. A score of 1 is not clinically acceptable, and a score of 4 is excellent. In addition, the teachers and evaluators were the same throughout the study. Research carried out by Quinn et al. (2003) aimed to compare the effectiveness of virtual reality simulation (Dentsim) and traditional phantom head simulators regarding dental skills acquisition. The study was well designed, with the participants consisting of novice dental students with no previous operative experience. Also, the students were divided into three groups. Group one participants were trained by traditional simulators. Group 2 participants were trained by traditional and VR simulators with the availability of an instructor for advice, while group 3 trained combined traditional and VR simulators with the advice on the only supplied by the VR software. Each student completed two class I cavity preparation on either traditional or VR simulators according to their group. And the students were given an introduction and instruction on what

type of cavity design was required in the study. The research results showed significant differences between the VR and conventional groups. Also, it stated that feedback and evaluation of VR-based skills acquisition for novice students is not adequate to be used as a singular method to evaluate student performance. This agrees with Al-Saud et al. (2017) study that the students preferred digital and tutor feedback when performing haptic exercises. The drawback of the study is there was a disproportion of time spent between the groups on the traditional and VR simulator, which has resulted in a biased result.

The intraoral scanner has gained popularity since its introduction in dentistry as a method of recording oral impressions for dental patients. Various studies have investigated the IOS scan precision compared to traditional impressions. The research has varied in investigating the accuracy of scans of unprepared full dental arches and in assessing the accuracy of reproducing crown preparations (Keeling et al., 2017; Ender et al., 2019). IOS can be used as a method to scan prepared typodont teeth transfer them as a 3D image. The images can be viewed by tutors and provides assessment and feedback to the dental students.

1.7.2.2 PrepCheck

PrepCheck is an assessment software that assess the dental students' preclinical procedures in prosthodontics. The advantage of prepCheck software is that it saves dental students’ crown preparations on a typodont as a 3D model. Also, the software allows comparison between the prepared and the unprepared tooth (Park et al., 2017). A study carried out by Kwon et

al. (2014) mentioned using prepCheck, and E4D Compare in preclinical education didn't improve dental student performance. The study stated that the dental students and the instructors weren't given adequate instruction on the digital technology E4D Compare and prepCheck, and as a result, it influenced the result of the study and might produce biased results, especially when the students did not have enough experience with these digital assessment tools. The addition of newly developed digital assessment tools is essential in preclinical dental education, and it may allow for more accurate assessment and feedback to dental students (Gratton et al., 2017). A study by Gratton et al. (2017) aimed to evaluate students' dental crown preparations by using the traditional visual assessment method and two types of digital assessment methods (prepCheck and Compare). The study was well designed with a large sample size of 79 2nd year dental students. Also, the traditional assessment and digital assessment were scored on a scale from 0 to 100. The traditional scores were based on a checklist of 13 categories. The study assigned three experienced clinicians to mark the dental students' preparations, with each clinician assigned a certain number of criteria to assess. As a result, the clinicians evaluated the same criteria for dental students' preparations. Also, the clinicians were trained and calibrated for the study. The study found a strong correlation between the two digital scores, but a weaker correlation between digital and traditional scoring. Evaluating dental students in the preclinical phase is essential to assess their manual skills. Supervising clinicians provide feedback and visual assessment for student preparations on typodont teeth. The assessment provided by clinicians should be consistent and objective. Inconsistent feedback with a wide range of

methods in the traditional visual assessment has resulted in a loss of feedback confidence from dental students. Also, survey results by Henzi et al. (2007) study, which aimed to evaluate the dental students' perspectives in regards to their clinical education, showed that the dental students feel the learning process is affected negatively by inconsistent feedback (Henzi et al., 2007). Dental students feel that the prepCheck is a beneficial learning tool, and they prefer it together with the instructor for feedback and assessment in preclinical education (Schepke et al., 2020). A study by Schepke et al. (2020) aimed to evaluate the consistency of the conventional assessment method and the instructor’s assessment with the aid of prepCheck. The study reported that the instructor’s assessments with prepCheck were noticeably different from the conventional method even though the same criteria were used. On the other hand, the assessment results were more consistent when the instructors used prepCheck. Although prepCheck requires equipment and time, it increases the consistency between instructors' assessments. Also, the students view prepCheck as an objective method of feedback and a valued education tool in preclinical dental education.

1.7.2.3 PrepAssistant

PrepAssistant is a 3D scanner that can scan a model tooth. The unprepared tooth can be used by the device to compare it with a student's prepared tooth. Also, the PrepAssistant can superimpose the instructor prepared tooth with the dental student's tooth and measure any differences present at a certain point of the preparation. The device (PrepAssistant) has been reported as not being suitable to be used as a single method for assessment

due to the difficulty of calculating a single grade and, the inability to assess all the relevant criteria of acceptable dental crown preparation (Taylor et al., 2013). A study by Taylor et al. (2013) aimed to compare the grades of two experienced assessors with assessments from a PrepAssistant digital scanner. The study evaluated dental crown preparations on typodont teeth carried out in a preclinical operative course. Also, the study examined the level of inter-examiner and intra-examiner agreement of the experienced evaluators. Finally, the study examined the accuracy level of the PrepAssistant. The sample consisted of 3rd year undergraduate dental students, who produced 78 preparations to be assessed in the study. Although the study didn't mention the participant sample size, it was well designed with the participants undertaking standardization exercises prior to participation in the study with clear instructions on the type of crown preparation required to be given to the dental students. Also, the teeth were randomised to prevent any bias in the study. The two experienced staff assessed each of the preparations independently at a separate time to prevent any discussion of the grades. The study results showed a low level of inter-examiner reliability for the assessment grades. Also, the results stated that the two experienced assessors had the highest agreement. Then the peer assessment had a poor agreement with the experienced assessors. Finally, no agreement was found between the digital scanning device when compared with the other assessment methods. The limitation of the Kavo PrepAssistant is that it assesses the differences in measurements as it is a pure scanner. When assessing a dental crown preparation, several factors affect the quality of the preparation. These factors include surface roughness and the finish line quality, which can be evaluated during a conventional

assessment but can’t be assessed by the Kavo PrepAssistant. Another limitation of the Kavo PrepAssistant is that it doesn’t provide a mark for dental preparation when used independently. While more modern technologies can overcome the limitation of the Kavo PrepAssistant, there is some difficulty when comparing digital assessments methods with traditional assessments (Taylor et al., 2013). The Kavo PrepAssistant System is a 3D scanner that can measure geometric differences between different dental preparations. It eliminates the need to calibrate other examiners. The Kavo PrepAssistant is a useful preclinical tool. Nonetheless, it has some limitations, as it can’t assess the finish line and surface smoothness of the preparation, which is an essential part of a good dental crown preparation. Another limitation is that the software for the assessment of paediatric dental procedures has not been developed (Taylor et al., 2013). Recently, several technological systems have been used for the preclinical training of dental students. These technologies include DentSim, Virtual Reality Dental Training System (VRDTS), and Kavo PrepAssistant. The main advantages of these systems are saving time and effort for dental staff and helping dental students recognize any mistakes present in their dental preparations. The Kavo PrepAssistant system generates a 3D view of the dental preparation. It has the advantage of comparing student dental preparation images with an instructor's preparation image and measuring any differences between any specified points (Cardoso et al., 2006). Kavo PrepAssistant doesn’t produce a result of a student’s preparation but a sequence of small preparation results. Uniformity of the finish line and surface smoothness are essential parameters in the dental crown preparation that the PrepAssistant software can’t assess (Cardoso et al.,

2006). A study by Cardoso et al. (2006) used the Kavo PrepAssistant software to assess cavity preparations made by dental students. The research planned to generate 70% of the grades by the PrepAssistant, and the other 30% from visual evaluations to assess the finish line and surface roughness. This method was compared to a 100% instructor assessment. The results showed that there were no statistical differences between the assessment methods. The study also mentioned that two students who passed the digital evaluation had an unacceptable preparation and didn't deserve to pass, which highlights one of the problems of relying on an automatic grading system from a computer that has no clinical relevance. The limitation of the study was a small sample size which the authors acknowledged, and another limitation is that the digital assessment couldn't produce a final result of the preparation. The study concluded that Kavo PrepAssistant couldn't be used alone in marking the preclinical performance of dental students, but the grades provided could be taken into consideration along with the traditional assessment method (Cardoso et al., 2006). The inconsistent preclinical assessment might lead students to focus on the grades of their preparations rather than the actual learning process of the dental procedures. This issue might be minimized by training and calibrating the staff members (Kateeb et al., 2017).

1.7.2.4 Fair Grader software

A study by Kateeb et al. (2017) examined the efficiency of the digital grading software Nissin Fair Grader 100 and four staff members' assessments by comparing the grades from assessing dental student preparations. The Fair Grader 100 software scans the prepared tooth and compares it to an ideal

preparation. The software also produces a grade for the ideal prepared tooth. The study was well designed with a good sample size of 96 teeth prepared by fourth-year dental students at Al-Quds university. The typodont teeth were coded and blinded and presented to four examiners for assessment. The examiners were staff members specializing in prosthodontics. They were calibrated with an ideal standard preparation. The Fair Grader 100 scans and superimposes the preparation on a gold standard preparation in a 3D image. The Software gives a grade from 0 to 100 and measures any difference in reduction from an ideal standard set by the software. After one month, a random sample of 20 teeth was selected for re-evaluation by the examiners. The results of the study stated that there were significant differences between the examiners and the digital grading system. The limitation of the Kateeb et al. (2017) study is that the visual grading by the examiners and the digital grading system measured different preparation criteria, which might explain the disagreement between the two types of assessment. The Nissin grading system can't assess the surface smoothness of the preparation and finish line, which are essential criteria in successful dental crown preparations. These criteria were only graded by visual assessment in the study.

1.7.2.5 Laser Scanner es1

A study by Esser et al. (2006) aimed to evaluate visual and digital assessment for dental crown preparation. The digital method consisted of a laser scanner 'es1' and then a software called 'scan 3d' and 'match 3d', which produced the results for dental preparation. The study was well designed, with the dental students briefed on the type of dental crown

preparation required. The study consisted of a sample size of 36 and five evaluators. A set of criteria were set for the evaluators to assess the preparation and for the students to view at the start of the study. The study results stated that there was a higher correlation in the digital assessment than the visual assessments. The drawback of the study is that the digital assessment couldn’t measure or assess the presence of undercuts or the quality of the preparation surface, which makes the assessment results weak and incomplete, as the undercut and the surface smoothness are essential parts of crown preparations.

In summary, in various studies the literature has reported comparisons between conventional visual assessment and digital automatic assessment. The studies have shown that digital assessment methods were more objective and more consistent than conventional assessments. However, there is a limitation of the digital assessments used. The limitations of digital methods consist of the inability to produce a clinically relevant final result for the dental student preparation or that they cannot measure all the essential criteria in dental crown preparations. This leads to the need for a staff member to assess dental student crown preparations. (Esser et al., 2006; Renne et al., 2013; Kwon et al., 2014). Automated digital assessment cannot be recommended as a primary assessment method based on the current evidence.

1.8 Covid-19 and Remote Assessment

World Health Organization (WHO) declared Covid-19 a pandemic in March 2020. All universities around the world moved to online didactic teaching for a period of time, and in the case of dentistry, the teaching moved back to

non-patient-facing teaching when it was safe to do so. This led to a reduction in clinical exposure for the dental students. As a result, continued training and skills development has become necessary for newly graduating dentists. Also, newly graduating dentists in the United Kingdom must sit clinical assessments before starting the dental foundation training (Doughty and Moshkun, 2020). Validating a 3D image assessment could benefit newly graduated dentists, as they could practice a dental procedure at their clinic on typodont teeth, save it as a 3D image and ask for an assessment remotely, which might benefit the dentist’s progression throughout their training. With an ongoing move towards continued professional development within dentistry, a set of prepared typodont teeth can be sent to an expert in the field for opinion or assessment by scanning it into a 3D image (Physical Digitization). There is a need for studies comparing traditional visual assessment and digital assessment for dental students' crown and cavity preparations.

1.9 Motivation

The literature lacks any scoring system for routine paediatric dental procedures applied for the traditional dental simulator, such as stainless-steel crown preparation or pulpotomy of primary teeth, to assess the improvement of skills of dental students. The development and validation of a scoring system could help evaluate dental students and reduce inter-examiner variability in the preclinical stage of dental training.

In order to maximize the educational value of the use of simulation in dental education, further investigation is needed on the effect of using a validated scoring system on the student preclinical learning process. The development

of scoring systems could help assess student performance more reliably and help assess different available simulators and their benefits in the preclinical stage of dental training. Digital assessment is computer software that gives an assessment score of a dental preparation. Although the literature reports that digital assessment methods are more accurate and consistent than visual assessment, the digital assessment software available is not successful in assessing the dental crown preparations criteria (Taylor et al., 2013). The dental crown preparation is required to be evaluated by a clinician to assess if it is acceptable preparation. Further investigation of the student preclinical learning with the phantom head simulator with a validated scoring system on routine paediatric dental procedures is needed, which will benefit the educational value of dental simulator learning. With limited information on the digital assessment tools, this study aimed to use an intraoral scanner to produce a 3D digital image of ideal and not ideal pulpotomy cavity preparations of typodont teeth. Then, the digital images and the prepared typodont teeth were evaluated using the traditional visual assessment method with a marking system based on scores from 1 to 3. We aimed to evaluate the consistency of the assessment scores of the typodont teeth and their 3D images, with the assessor using the same assessment system for both evaluations in the pulpotomy paediatric procedure. Currently, the literature lacks any study comparing a traditional visual assessment with a 3D image assessment (visually).

Chapter 2 Aim of The Research

The study aimed to assess the consistency of the participant's assessment system scores using traditional assessment methods on assessing typodont teeth and 3D images of those preparations.

Chapter 3 covers a preliminary investigation into the need for further preclinical training for paediatric dental procedures through a questionnaire (Appendix 1 and Appendix 2) aimed at undergraduate dental students and postgraduate dental students in the paediatric dentistry department. The results showed that the majority of the participants wished to have further preclinical training on the pulpotomy paediatric dental procedure.

Chapter 4, we used the most mentioned procedure chosen by the participants in Chapter 3 and developed an assessment system relevant to that procedure. The principal researcher carried out pulpotomy dental procedures on five typodont teeth with different cavity outlines and preparations (Figure 1). The five typodont teeth were scanned with an intraoral scanner and saved as 3D images. The participants used the assessment system (Appendix 6) to assess five typodont teeth and five 3D images.

Research Questions

1. Can a standardised scoring system be developed for a routine paediatric dental procedure (pulpotomy preparation) performed on a typodont Frasaco plastic molar tooth with a wax pulp?
2. Can the assessment be carried out on the tooth preparations viewed in 3D scans?

3. Can the two assessments produce consistent feedback when carried out by paediatric dentistry consultants and clinical staff teaching undergraduate dental students?

Null Hypothesis

The null hypothesis for this research project was that there would be no statistically significant difference between the assessment scores of the typodont teeth assessment and the 3D images assessment.

Chapter 3 Preliminary study

3.1 Aims and Objective

The study aimed to identify the perceived participant's needs for further preclinical training on routine paediatric dental procedures for dental students.

The study aimed to assess undergraduate and postgraduate dental students' preclinical training and educational needs through a questionnaire.

3.2 Methodology (Preliminary Study)

The preliminary study aimed to identify the need for further preclinical training on routine paediatric dental procedures for dental students. Also, the preliminary study assessed the preclinical training and educational needs of the undergraduate and postgraduate dental students through a questionnaire shown in Appendix 1 and Appendix 2. The principal researcher designed and circulated a questionnaire to the volunteer participants. The questionnaire included routine dental treatment in paediatric dentistry, such as caries removal in class II cavity preparation, pulpotomy, and stainless-steel crowns (SSC) preparation. The participants choose which procedure they wish to have additional preclinical training. A Likert scale from 1 to 10 was used to measure the confidence level of participants in performing their 1st dental procedures on actual patients in a clinical setting. Also, the Likert scale measures the participant’s confidence in performing routine paediatric dental procedures such as caries removal in class II cavity preparation, SSC preparation, and Pulpotomy. The undergraduate questionnaire (Appendix 1) contains five questions, while the

postgraduate questionnaire (Appendix 2) includes four questions. The questionnaires are purposely designed in a simple and short form, as it's not the primary research goal. The principal researcher identified the undergraduate and the postgraduate dental participants through the U.G. Year Three Lead and P.G. students' Head of Department. The principal researcher emailed the year three lead and head of department, explaining the purpose of the questionnaire and the study. Also, the Year Three Lead and Head of Department sent an email to U.G. and P.G. students one week before a certain lecture. The email explained the purpose of the questionnaire and invited the dental students to participate in the study. After identifying a lecture for the undergraduate and postgraduate participants, the principal researcher briefly explained the research with an oral presentation. Also, the participants were provided with a paper copy of the participant information sheet (Appendix 3). All participants who agreed to participate in the study signed a consent form before completing the questionnaire. The questionnaire assessed the participant's confidence level in carrying out routine paediatric dental procedures and identified which paediatric dental procedure they would prefer further preclinical training.

3.3 Ethical approval

Ethical approval for the study was granted by the Dental Research Ethics Committee (DREC) of the University of Leeds at Appendix 5. Written consent was obtained from all participants.

Ethical approval number (011019/A.Q./286)

Ethical approval date (9.01.2020)

3.4 Selection criteria

The participants included 3rd year undergraduate dental students and 1st year postgraduate students in the paediatric department of the University of Leeds.

3.5 Student recruitment

The researcher contacted and explained the research purpose to the undergraduate year three lead and the postgraduate head of department (HoD). Also, the number of potential participants was identified from the UG year three lead and PG HoD. The year lead and HoD sent an email before a specific lecture containing information about the research to all potential participants of dental students. The email was sent to the participants three days prior to a lecture to consider participating in the study. On the day of collecting the data, the researcher attended one of the lectures for the UG students. The principal researcher carried out a brief oral explanation (5 minutes) to the students who attended the lecture. The oral presentation explained the research process and steps. The principal researcher provided a paper copy of the consent form and the questionnaire to the volunteer participants who agreed to participate in the study. For the PG participants, an email was sent by the head of department explaining the research purpose. The principal researcher carried out a brief explanation of the research to all students attending the lecture. Also, all students were provided with a participant information sheet. All participants who agreed to

participate in the study were provided with a consent form (Appendix 4) and a questionnaire. The students had one week to decide if they want to participate in this research.

3.6 Ethical considerations

The dental students were assured that their participation was entirely voluntary and had the right to refuse participation in the research. The participants were assured that the study would have no effects on their dental studies. The participants were not able to withdraw after completing the questionnaire because the questionnaires were anonymised. The participants had the right to refuse participation in the study, and if the participant did not wish to participate, the consent form would not be signed. This study was a low-risk study because no personal details were obtained as the questionnaire is anonymous. Data collected (Consent and questionnaire) are stored safely in a locked cabinet in a secure office at Leeds University level 6.

3.7 Results (Preliminary study)

The total number of participants invited was 60 dental students. The total number of participants who agreed to take part in the study was 55 dental students. The participants consisted of 50 3rd year undergraduate dental students and five 1st year postgraduate students in paediatric dentistry. The response rate was 90% for the undergraduate students and 100% for the 1st years PG students.

3.7.1 Undergraduate Questionnaire

Table 1 shows the answers to the first question of the questionnaire distributed to undergraduate participants. The 1st question assesses how useful the phantom head training is in the preclinical paediatric dental training for the UG participants. A score of 10 equals very useful training, and a score of 1 equals not useful training. The total response to the question was 50 UG participants. The results are demonstrated in Table 1, which shows 38% of the participants chose answers between 8-10. While 44% choose to answer 5 to 7 regarding how they believe the phantom head exercises are beneficial in paediatric dental training. Also, 12% of the participants did not have any paediatric preclinical training at the study time, so they didn't answer the question.

Table 1 Usefulness of phantom head in paediatric dentistry preclinical training

How useful are phantom head exercises in paediatric dental procedure training?			
		Frequency	Percent
Valid	N/A	6	12
	1-4	3	6
	5-7	22	44
	8-10	19	38
	Total (n)	50	100

The 2nd question in the questionnaire evaluates preclinical training of different paediatric dental procedures for the participant's 1st clinical experience. Table 2 provides an overview of the preparation of preclinical

training on different paediatric dental procedures for the UG participants' first clinical experience. The majority of the participants, 46%, choose answers 5-7. Furthermore, 14% of the participants chose 8-10, and 11 participants (22%) didn't carry out or didn't have enough exposure to paediatric preclinical training phase and couldn't assess preparation to carry out treatment on an actual patient. As a result, the undergraduate participants couldn't assess the preclinical dental training and chose N/A.

Table 2 Preparation of preclinical training of different paediatric dental procedures for the first clinical experience?

Do you feel preclinical training in different paediatric dental procedures prepared you for your first clinical experience?			
		Frequency	Percent
Valid	N/A	11	22
	1-4	9	18
	5-7	23	46
	8-10	7	14
	Total (n)	50	100

Table 3 demonstrates the results of the 3rd question of the Undergraduate (UG) questionnaire. This question is only presented in the UG questionnaire. The question measures the confidence level of the UG participants in performing their 1st dental procedure on an actual patient. The answers were distributed on a wide range of responses, with 16% choosing 8-10 while 52% of the participants chose between 5-7

Table 3 confidence level for the UG participants on performing their 1st clinical procedure. This question was present only in the UG questionnaire.

How confident you were/are to perform your 1st dental procedure on an actual patient?			
		Frequency	Percent
Valid	1-4	15	30
	5-7	26	52
	8-10	9	18
	Total (n)	50	100

The 4th question of the UG questionnaire is shown in Table 4. The question evaluates the UG participant's confidence in performing pulpotomy paediatric dental procedures. The majority of the participants (72%) choose answers 1 to 4. Also, 24% choose 5-7 as a confidence level. The scores 8 to ten are missing from Table 4 as none of the participants chose these answers as a confidence level pulpotomy dental procedure.

Table 4 Undergraduate participant's confidence levels on performing pulpotomy dental procedure

How confident are you in performing the following paediatric dental procedures: Pulpotomy			
		Frequency	Percent
Valid	N/A	2	4
	1-4	36	72
	5-7	12	24
	8-10	0	0
	Total (n)	50	100

Table 5 shows the results of the UG participant's confidence level in performing stainless steel crown preparations. The results show 46% of the participants choose 1 to 4 as a confidence level, while 48% of the

participants choose answers 5-7 as a confidence level performing SSC preparation.

Table 5 Undergraduate participant's confidence levels on performing Stainless steel crowns preparations

		Frequency	Percent
Valid	N/A	2	4
	1-4	23	46
	5-7	24	48
	8-10	1	2
	Total (n)	50	100

The UG participant's confidence level in caries removal and cavity preparations results is shown in Table 6. 14% of the participants chose the score from 1 to 4. The score 5-7 consists of 40% of the participants, while 42% chose the answers 8 to 10 as a confidence level to carry out caries removal and cavity preparations dental procedures.

Table 6 Undergraduate participant's confidence levels on performing Caries removal and cavity preparation

How confident are you in performing the following paediatric dental procedures: Caries removal and cavity preparation			
		Frequency	Percent
Valid	N/A	2	4
	1-4	7	14
	5-7	20	40
	8-10	21	42
	Total (n)	50	100

The answers to the 5th question of the UG questionnaire are shown in Table 7. The question states if the participants would welcome the opportunity for further preclinical training on paediatric dental procedures. If the participants answer yes, the dental students could choose any of the three following dental procedures: 1- Pulpotomy, 2- SSC preparations, 3- caries removal cavity preparations. The participants could choose more than one answer. The results in Table 7 show 100% of the UG participants would welcome further preclinical paediatric dental training.

Table 7 If the Undergraduate participants wish to have further preclinical paediatric dental training

Would you welcome further preclinical training?			
		Frequency	Percent
Pulpotomy	N/A	1	2
	Yes	49	98
	Total (n)	50	100
SSC	N/A	6	12
	Yes	44	88
	Total (n)	50	100
Caries removal and cavity preparation	N/A	16	32
	Yes	34	68
	Total (n)	50	100

The 1st procedure for the participants who wish to have further preclinical training is Pulpotomy. The results showed that 98% of the participants would welcome further preclinical training on the pulpotomy dental procedure. The UG participants would welcome further preclinical training on stainless steel crowns (SSC) preparations are 88%. Finally, the participants who would like

further preclinical training on caries removal and cavity preparations are 68% of the participants.

3.7.2 Postgraduate Participant Questionnaire

Table 8 shows the answer to the first question of the questionnaire distributed to the postgraduate participants in the paediatric dentistry department. The 1st question measures how useful skill lab exercises in preclinical paediatric dental training is for PG participants. The total response to the question was five PG participants. The results are limited to two answers. 80% of the PG students choose 8, while 20% choose 10 as the usefulness of skill lab exercises in paediatric dentistry preclinical training.

Table 8 Usefulness of skill lab exercises in paediatric dentistry preclinical training

How useful are skill lab exercises in paediatric dental procedure training?			
		Frequency	Percent
Valid	1-4	0	0
	5-7	0	0
	8-10	5	100
	Total (n)	5	100

The 2nd question results for the PG participants are shown in Table 9. The question measured the preclinical preparation of paediatric dental procedures for the PG participants to deliver treatment on actual patients. The PG participant's questionnaire results are confined to two answers. 80% of the PG participants chose 8, while 20% chose 5 as a level of preparation for the preclinical training.

Table 9 Preparation of preclinical training of different paediatric dental procedures for the first paediatric clinical experience

Do you feel skill lab training of different paediatric dental procedures prepared you to carry out treatment on actual patients?			
		Frequency	Percent
Valid	1-4	0	0
	5-7	1	20
	8-10	4	80
	Total (n)	5	100

The confidence level results on performing pulpotomy dental procedure for the PG participants are shown in Table 10. The results revealed that 80% of the PG participants choose 8 while 20% choose 3 as a confidence level to carry out the pulpotomy dental procedure.

Table 10 Postgraduate participants confidence levels on performing pulpotomy dental procedure

How confident are you in performing the following paediatric dental procedures: Pulpotomy			
		Frequency	Percent
	1-4	1	20
	5-7	0	0
	8-10	4	80
	Total (n)	5	100

Table 11 shows the confidence level for the PG participants in carrying out Stainless steel crowns (SSC) preparation. The results are range from 6 to 9. 40% of the PG students choose 8 as a level of confidence, while 20% of the

students choose each of the following answers 6, 7, and 9 as confidence level to carry out SSC preparations.

Table 11 Postgraduate participants confidence levels on performing Stainless steel crowns preparation (SSC)

How confident are you in performing the following paediatric dental procedures: Stainless steel crowns preparation (SSC)			
		Frequency	Percent
Valid	1-4	0	0
	5-7	2	40
	8-10	3	60
	Total (n)	5	100

Table 12 demonstrates the PG participants' confidence level results on caries removal and cavity preparation dental procedure. The results show that 60% of the PG students choose 9, and 40% choose 10 as a confidence level to carry out pulpotomy dental procedure.

Table 12 Postgraduate participants confidence levels on performing Caries removal and Cavity preparation

How confident are you in performing the following paediatric dental procedures: Caries removal and Cavity preparation			
		Frequency	Percent
Valid	1-4	0	0
	5-7	0	0
	8-10	5	100
	Total (n)	5	100

The answers for the 4th question of the PG questionnaire are shown in Table 13. The question states if the participants would welcome the opportunity for

further preclinical training on paediatric dental procedures. If the dental students answered yes, the participants would choose any of the three following dental procedures: Pulpotomy, SSC preparations, caries removal, and cavity preparations. The students could choose more than one answer. The results show 80% of the PG participants would welcome further preclinical paediatric dental training, and 20% declined the opportunity for further preclinical training on paediatric dental procedures.

Table 13 If the postgraduate participants wish to have further preclinical paediatric dental training

Would you welcome the opportunity for further preclinical training on paediatric dental procedures?			
		Frequency	Percent
Valid	No	1	20
	Yes	4	80
	Total (n)	5	100

Table 14 demonstrates the PG participants who wish to have further preclinical training on Pulpotomy, SSC, caries removal, and cavity preparations. The results show that 60% of the participants would welcome further preclinical training on the pulpotomy dental procedure, and only 20% of the PG participants would like further preclinical experience on SSC preparation. Finally, 100% of the PG participants wouldn’t want additional preclinical training on Caries removal and cavity preparations.

Table 14 The number of postgraduate participants who wish to have further preclinical training on Pulpotomy, SSC and Caries removal and Cavity preparation:

Would you welcome further preclinical training?			
		Frequency	Percent
Pulpotomy	N/A	2	40
	Yes	3	60
	Total	5	100
SSC	N/A	4	80
	Yes	1	20
	Total	5	100
Caries removal and cavity preparation	N/A	5	100

3.8 Discussion (Preliminary study)

The Preliminary Study of the research aimed to identify the need for additional preclinical training on routine paediatric dental procedures for UG and PG participants. Also, the preliminary study assessed the preclinical phantom head training of the UG and the PG participants through a questionnaire shown in *Appendix 1, Appendix 2*. The preliminary study aimed to identify which procedures the participants wished to have further training on a routine paediatric dental procedure and record a baseline result of the preclinical preparations on paediatric dental procedures. The results showed that the majority of the participants chose Pulpotomy dental procedure to have additional preclinical training. Due to this result, Pulpotomy is the procedure of choice for the 2nd part of the study. The results showed a high level of requests for paediatric dental procedures in

the questionnaire for the UG participants. A study by Stewart et al. (2010) looked at the logbook of 4th and 5th year UG dental students. The results showed that the students had the least experience with pulpotomy paediatric dental procedures, which is consistent with the questionnaire results of the study, as it is the procedure chosen by most of the students to have further practice on.

PG participants also desired more preclinical training on paediatric procedures, even though PG participants were expected to have a higher level of experience than UG participants. Only one PG participant didn't wish to have further preclinical training. Considering the small sample size (five) of the PG participants, they had more experience than the UG participants, which is reflected in the results of the confidence level in carrying out routine paediatric dental procedures shown in *Table 10, Table 11,* and *Table 12*. One evident issue while collecting data is that some of the UG participants didn't start the paediatric preclinical training and did not have enough information to participate.

Chapter 4 Main study

4.1 Main Study Aims and Objectives

4.1.1 Aims

The main study aimed to develop and validate a standardised scoring system to be used by staff teaching UG and PG dental students

for a routine paediatric dental procedure (pulpotomy) carried out on a typodont tooth mounted in a phantom head simulator**.**

The second aim was to evaluate assessors' scoring consistency in assessing the typodont prepared teeth directly and on scanned 3D images of the same preparations.

4.1.2 Objectives

1. To design and implement a scoring system for a paediatric dental procedure on typodont teeth in the traditional phantom head simulator.
2. Assess the consistency of the scores and feedback for the prepared typodont teeth among paediatric dentistry consultants and clinical staff teaching undergraduate students.
3. Determine whether consultants, clinical staff, and postgraduate participants teaching UG students gave similar scores for the preparations on the typodont teeth and the 3D scanned images (Digital teeth).
4. Evaluate if the typodont and 3D image assessments are interchangeable.

4.2 Methodology Main study

The principal researcher carried out five different pulpotomy preparations on Frasaco (AK- 6/2 ZPUW) typodont second primary molar teeth containing wax pulps mounted on a phantom head simulator.

The preparations were carried out with a high-speed handpiece and diamond bur (ISO237-010M) and a slow speed handpiece with rose head burs. The researcher used a sharp straight probe, excavators, and a dental mirror, which helped carry out and assess the dental preparations. The pulp was removed with a hand excavator. The five preparations consisted of varying standards and covered common errors in the pulpotomy procedure. The preparations were assessed with a Paediatric Dental Consultant to ensure that they were acceptable and not acceptable preparations. The Omnicam Intraoral scanner (IOS) from Dentsply Sirona was used to scan each of the five prepared typodont teeth to produce five 3D images for assessment by the participants.

The scanned 3D images were viewed by the participants on a program software called MeshLab (Cignoni et al., 2008). MeshLab is a software in which a 3D image can be edited and viewed. The software allowed the participants to view and rotate the 3D images to show the detail of all the tooth surfaces. A web page was created with the five scanned images to be used by any participants who would wish to complete assessments at a convenient time https://leedsdigitaldentistry.com/PulpotomyScoring/.

The prepared teeth with identification codes were mounted on an acrylic block in random order (*Figure 1)*. This allowed the principal researcher to sanitize

the block between each use by the participants. The sample block was delivered to each participant with a scoring sheet (*Appendix 6)*.

Figure 1 shows the six typodont teeth that were presented to all participants. The first tooth (Number zero) was not prepared and only demonstrated dental caries. The participant assessed tooth numbers one to five.

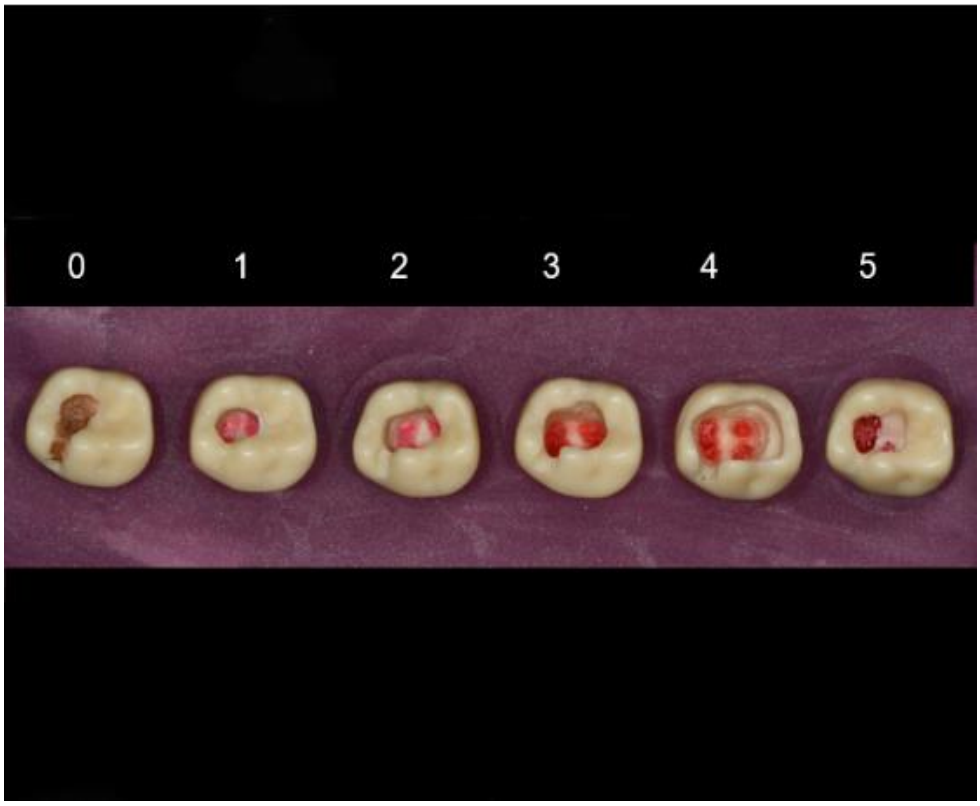


Figure 1. Six typodont teeth used in the study.

The five dental preparations consisted of two clinically acceptable preparations (Typodont teeth numbers two and three) as determined by the principal researcher in agreement with the Consultant. Typodont tooth number one had an under extended preparation (too small) and only partial removal of the pulp tissue. Typodont tooth (number four) had an overextended preparation (too large). The typodont tooth (number five) preparation had an under-extended preparation with incomplete deroofing of the pulp chamber and incomplete pulp tissue removal. Calibration and confirmation of the cavity

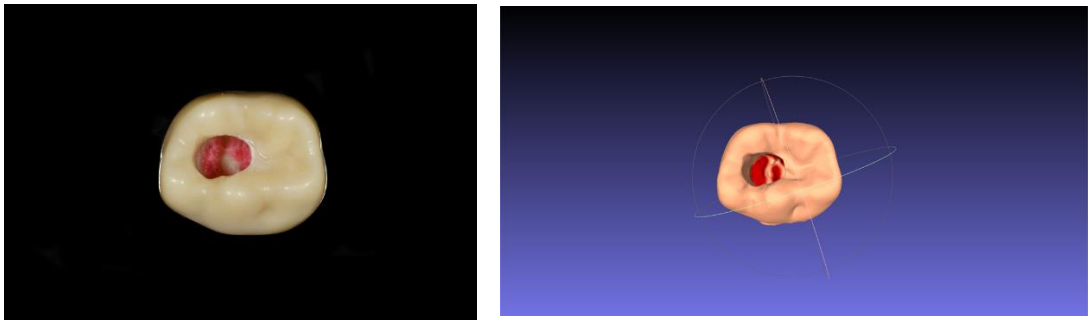
design of the five prepared teeth were carried out by one of the supervisors with experience in these procedures.

Figure 2 shows tooth number zero, which was used to simulate the dental caries lesion, and no preparation or assessment was carried out on this typodont tooth.

Figure 2. Typodont tooth number zero

At the beginning of the assessments, the principal researcher carried out a brief oral explanation about the aim of the research for each participant and provided a participant information sheet (*Appendix 7)*. A Consent Form (*Appendix 8)* was signed by all the participants who agreed to take part in the research. The participants were divided into two groups, with one group starting the assessment with the typodont teeth and the other group with the 3D images. Following this, the principal researcher either presented the typodont teeth or a portable laptop for the participants to view the 3D images. The same laptop was used for the entire study to prevent any bias in the results, so the same screen was used for all participants to assess the 3D images. The participants were randomized in the order they scored the typodont teeth and the 3D images.

Figure 3 illustrates tooth number 1 and the 3D image. The typodont tooth has an underextended preparation and incomplete pulp tissue removal.

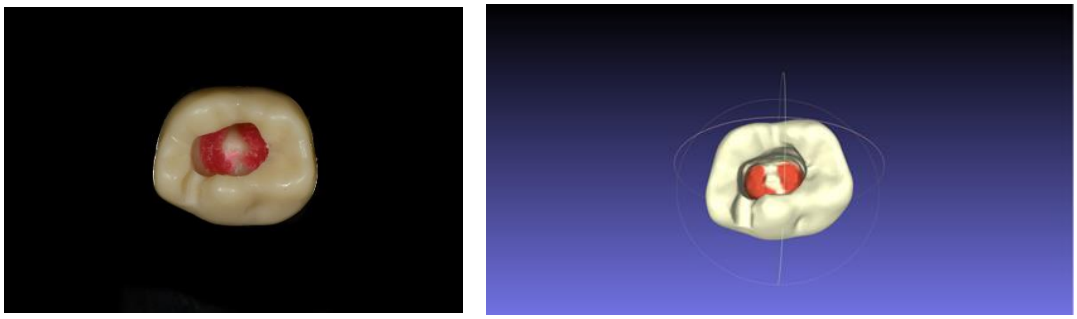


(a) **(b)**

Figure 3. (a) Typodont tooth and (b) 3D image of tooth number 1

*(b***)**

Figure 4 shows tooth number 2 and the 3D image. The preparation of the typodont tooth is clinically acceptable with complete deroofing and pulp tissue removal.



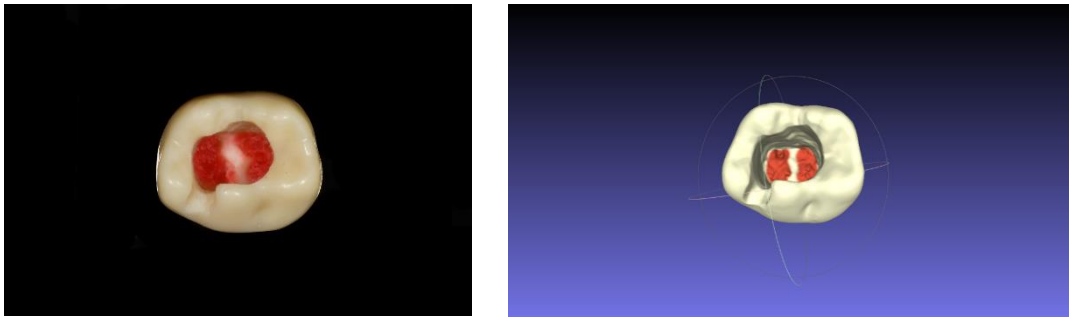
(a) **(b)**

Figure 4. (a) Typodont tooth and (b) 3D image of tooth number 2

Tooth number 3 and the 3D image are shown in

*(b***)**

Figure 5. The tooth has a clinically acceptable preparation and complete deroofing of the pulp chamber and pulp tissue removal.

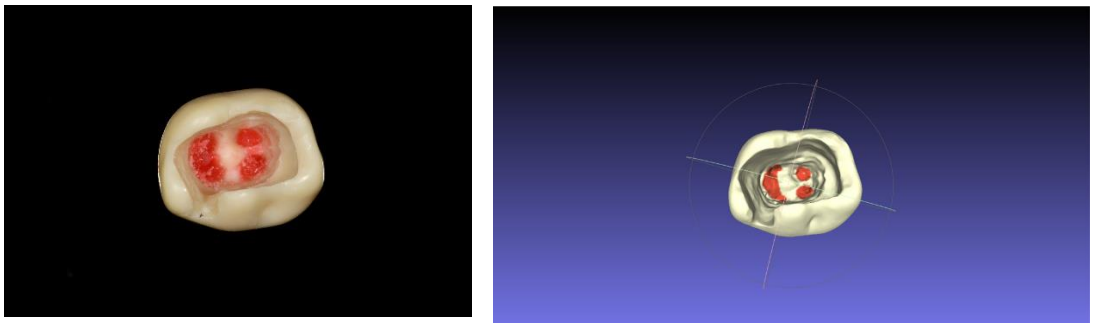


(a) **(b)**

Figure 5. (a) Typodont tooth and (b) 3D image of tooth number 3

*(b***)**

Figure 6 shows tooth number 4 and the scanned 3D image. The tooth has an over extended preparation and complete pulp tissue removal and shows only pulp remaining in the openings of the canals.

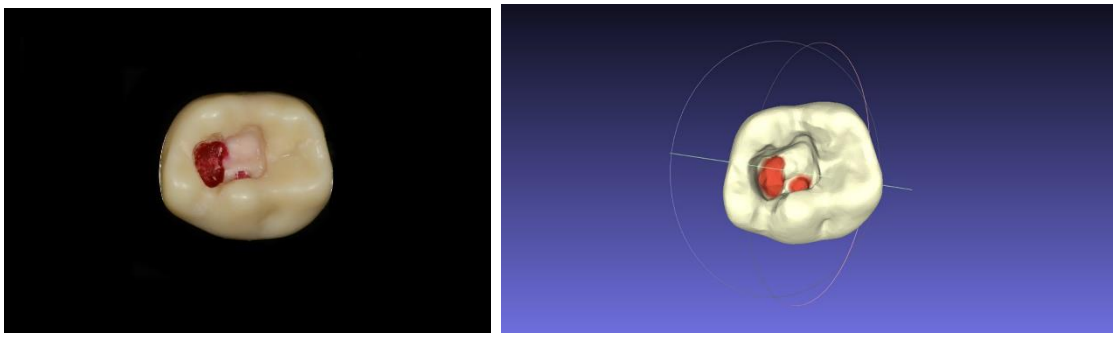


(a) **(b)**

Figure 6. (a) Typodont tooth and (b) 3D image of tooth number 4

(b)

Figure 7 demonstrates tooth number 5 and the 3D image. The tooth has underextended preparation with incomplete deroofing of the pulp chamber.



(a) **(b)**

Figure 7. (a) Typodont tooth and (b) 3D image of tooth number 5

The five prepared typodont teeth were scanned with an intraoral scanner and transferred into a 3D file. The prepared typodont teeth and the 3D images were submitted to each participant for assessment, with a scoring system relevant to the dental procedure. The participants were provided with an instruction sheet containing a radiograph with caries matching that in the simulated cavity and a picture of an oral cavity with a carious lower primary molar to allow them to assess the extent of the decay in the prepared tooth (*Appendix 6).* The participants were requested to evaluate the prepared typodont teeth and the digital teeth with the following marking criteria of the cavity design and preparation: correct access location, cavity outline, pulp chamber roof removal, and pulp removal. After each participant returned the typodont teeth and their scores, the teeth were cleaned with alcohol before giving them to the next participant. The assessment process included repeat scoring of the preparations after two weeks by 10% of the participants to

assess intra-assessor variability. After at least three days from the first scoring, the assessment of the 3D images or typodont teeth was presented to the participants to attempt to decrease any memory or bias being introduced into the scoring.

4.3 Ethical approval

This study was approved by the Dental Research Ethics Committee (DREC), University of Leeds. The DREC approval confirmation is shown in *Appendix 9.* Written consent was obtained from all participants.

Ethical approval number (301120/A.Q./311).

Ethical approval date (22/02/2021).

4.4 Scoring System

The scoring system (*Appendix 6)* was developed by the principal researcher. It was developed to be clinically relevant to the procedure being assessed (pulpotomy). The scoring categories cover relevant clinical aspects of the procedure and the clinical impact of the different preparations. The scoring system is divided into three categories: good scores 3, acceptable scores 2, unacceptable scores 1 for each criteria. The principal researcher designed a guide sheet for the participants to justify each score they gave (*Appendix 6)*. A comments box was added to justify the scores given and to comment on the preparations.

The 1st category assessed was the access (cavity) outline. Score 3 is awarded if an appropriate cavity outline is produced with no further adjustment required; Score 2 if the access cavity is underextended, while score 1 is for an overextended cavity. Underextended cavity scores are higher than

overextended cavity because it is correctable and considered less of a fault than overextended cavity outline. The 2nd category is the access location in regards to the pulp chamber. Score 3 is given if the access site is appropriately placed, score 2 for mild deviation, and score 3 is for moderate or severe deviation of the cavity location from the pulp chamber. The 3rd category is pulp chamber roof removal. Score 3 is for complete roof removal, score 2 for incomplete roof removal and/or any damage to the cavity walls. Score 1 is awarded in case of perforation. The 4th category is pulp tissue removal. Score 3 is given with complete pulp removal with clear access to the root openings; Score 2 for incomplete pulp removal with inadequate access to the root openings and score 1 for any damage to the pulpal floor.

4.5 Participants' selection criteria

The participants included paediatric dentistry consultants, specialist paediatirc dentists, specialty dentists, paediatric registrars, and postgraduate dental students who teach UG dental students in Paediatric Dentistry at the University of Leeds. The inclusion criteria included any member of staff and PG students in the paediatric dentistry department with clinical teaching experience of the undergraduate dental students. The reason for the inclusion of postgraduate students is that they supervise UG students in the clinic as part of the PG paediatric dentistry program, and many of them have teaching experience prior to undertaking postgraduate study. The participants were identified from the staff teaching undergraduate dental students at the University of Leeds. The Participant Information Sheet was emailed to the participants described the study details. After one week, another email was

sent again as a reminder, and if they are willing to take part, contact the primary researcher to sign a consent form.

4.6 Ethical considerations

The participants were assured that their participation was entirely voluntary, and they had the right to refuse participation in the research and could withdraw from the study at any point up until the results were being analyzed. The participants were assured that their scoring would be confidential and not identified in any research reports. They were assigned unique codes and a sheet of participants' names, and their codes were kept in a locked cabinet in a secure office on Level 6 of the Worsley Building University of Leeds. Data collected was stored safely in a locked cabinet in a secure office at Leeds University level 6. This information is only available to the principal researcher and lead supervisor. The principal researcher carried out a pulpotomy paediatric dental preparation on five typodont teeth. Due to Covid-19 protocols presented at the time of the study, and to prevent the risk of infection, the teeth were wiped and disinfected with alcohol and stored in a sterile plastic box before handing the teeth for assessment. The typodont teeth were disinfected again after collecting from each participant. The study methodology is considered to take approximately 20 minutes by the participants to carry out the assessment of typodont teeth and 3D images. The participants were informed that if they wished to have less direct contact with the researcher due to possible cross-infection due to Covid-19 concerns, the consent form, the scoring system, and the 3D image could be sent via email, and the only contact with the researcher would be to hand over the typodont teeth, which would be wiped and disinfected for each participant.

4.7 Participant's recruitment

The participants were identified from the staff teaching undergraduate dental students at the University of Leeds. The Participant Information Sheet was emailed to the participants described the study. After one week, another email was sent again as a reminder, and if they are willing to take part, contact the primary researcher to sign a consent form.

4.8 Results Main Study

The total number of eligible participants who were approached for the study was 34. The total number of participants who agreed to participate in this phase was 26. The participation level in the study was around 75% of the staff and PG dental students at the paediatric department. Some of the potential participants declined to take part in the study due to the heavy clinical load and inability to find time to participate. The sample size consisted of seven consultants and seven specialists in paediatric dentistry. Also, 12 participants were postgraduate students in paediatric dentistry of different levels.

The scoring took 20 minutes to complete by the participants to score five typodont teeth and five digital teeth, which was carried out on two separate days within an average period of a week to prevent any bias in the scoring. The time between the two visits varied from 7 to 21 days, depending on when staff were available. The raw data of the participants assessment scores of the typodont and the 3D images are demonstrated in Table 15, Table 16, Table 17, Table 18 and Table 19.

Table 15 Shows raw data of the assessment scores for tooth number 1

Participant Code	Tooth Type 0= Typodont 1= 3D image	Tooth Number	Access Score	Cavity Score	Deroofing	Pulp Ext
1	0	1	1	1	1	1
	1	1	3	1	2	2
2	0	1	3	2	2	2
	1	1	3	2	3	1
3	0	1	3	2	2	2
	1	1	2	2	2	2
4	0	1	2	2	2	2
	1	1	3	2	2	2
5	0	1	2	2	2	2
	1	1	3	2	2	2
6	0	1	3	2	2	2
	1	1	3	2	2	2
7	0	1	2	2	2	2
	1	1	1	2	2	2
8	0	1	2	2	2	2
	1	1	2	2	2	2
9	0	1	2	2	2	2
	1	1	2	2	2	2
10	0	1	1	2	2	2
	1	1	2	2	1	1
11	0	1	2	2	2	2
	1	1	2	2	2	2
12	0	1	1	2	2	2
	1	1	2	2	2	2
13	0	1	2	2	3	2
	1	1	2	2	2	2
14	0	1	2	2	2	2
	1	1	3	2	2	2
15	0	1	3	2	2	2
	1	1	3	2	1	2
16	0	1	2	2	2	2
	1	1	2	2	3	3
17	0	1	2	2	2	2
	1	1	2	2	2	2
18	0	1	3	2	3	2
	1	1	1	3	2	3
19	0	1	2	2	2	2
	1	1	2	2	2	2
20	0	1	2	2	2	2
	1	1	3	2	2	2
21	0	1	3	2	2	2
	1	1	3	2	2	2
22	0	1	3	2	2	2
	1	1	3	2	2	2
23	0	1	3	2	3	2
	1	1	1	2	2	2
24	0	1	1	2	2	2
	1	1	2	2	2	2
25	0	1	2	2	1	2
	1	1	2	2	1	1
26	0	1	2	2	2	2
	1	1	3	2	2	2
1 repeated score	0	1	1	2	1	1
	1	1	1	2	1	1
3 repeated score	0	1	2	2	2	2
	1	1	2	2	2	2

Table 16 shows raw data of the assessment scores for tooth number 2

Participant Code	Tooth Type 0= Typodont 1= 3D image	Tooth Number	Access Score	Cavity Score	Deroofing	Pulp Ext
1	0	2	2	2	2	2
	1	2	3	3	3	3
2	0	2	3	3	3	3
	1	2	3	3	2	3
3	0	2	2	2	2	3
	1	2	3	2	3	2
4	0	2	2	2	3	3
	1	2	3	3	3	3
5	0	2	3	3	3	3
	1	2	3	3	3	3
6	0	2	3	3	3	3
	1	2	3	3	3	3
7	0	2	3	3	2	2
	1	2	2	2	2	2
8	0	2	2	3	3	3
	1	2	3	2	2	2
9	0	2	3	3	3	3
	1	2	3	3	3	3
10	0	2	3	3	3	3
	1	2	3	3	3	3
11	0	2	2	2	2	2
	1	2	3	3	3	3
12	0	2	2	3	3	3
	1	2	3	3	3	3
13	0	2	3	2	3	3
	1	2	3	3	3	3
14	0	2	2	3	3	3
	1	2	3	3	3	3
15	0	2	3	2	2	3
	1	2	3	2	2	3
16	0	2	3	2	2	2
	1	2	3	3	3	3
17	0	2	2	2	3	3
	1	2	3	3	3	3
18	0	2	3	1	3	1
	1	2	2	3	3	3
19	0	2	3	3	2	3
	1	2	3	2	2	1
20	0	2	3	2	3	3
	1	2	3	3	3	2
21	0	2	3	2	2	2
	1	2	3	2	2	2
22	0	2	3	3	3	2
	1	2	3	3	3	2
23	0	2	2	2	2	2
	1	2	3	3	3	2
24	0	2	3	3	3	3
	1	2	3	2	2	2
25	0	2	3	2	2	3
	1	2	3	3	3	3
26	0	2	3	3	2	2
	1	2	3	2	2	2
1 repeated score	0	2	2	2	2	2
	1	2	3	3	3	2
3 repeated score	0	2	2	2	2	2
	1	2	2	3	2	2

Table 17 Shows raw data of the assessment scores of tooth number 3

Participant Code	Tooth Type 0= Typodont 1= 3D image	Tooth Number	Access Score	Cavity outline Score	Deroofing score	Pulp Ext score
1	0	3	3	2	3	3
	1	3	2	3	3	3
2	0	3	3	3	3	3
	1	3	3	3	3	3
3	0	3	3	3	3	3
	1	3	3	3	3	2
4	0	3	3	3	3	3
	1	3	3	3	3	3
5	0	3	3	3	3	3
	1	3	3	3	3	3
6	0	3	3	3	3	3
	1	3	3	3	3	3
7	0	3	3	3	3	2
	1	3	3	3	3	2
8	0	3	3	3	3	3
	1	3	3	3	2	2
9	0	3	2	3	2	2
	1	3	2	2	3	3
10	0	3	3	2	3	3
	1	3	3	1	1	1
11	0	3	3	3	3	3
	1	3	3	1	3	3
12	0	3	3	1	2	3
	1	3	3	3	3	3
13	0	3	3	3	3	3
	1	3	3	3	3	3
14	0	3	3	3	3	2
	1	3	3	3	3	3
15	0	3	3	3	3	3
	1	3	3	3	3	3
16	0	3	3	3	3	3
	1	3	3	1	2	1
17	0	3	3	3	3	3
	1	3	3	3	3	3
18	0	3	3	2	1	1
	1	3	2	1	3	3
19	0	3	3	3	3	3
	1	3	3	3	2	3
20	0	3	3	3	2	2
	1	3	3	3	3	1
21	0	3	3	3	3	3
	1	3	3	1	3	3
22	0	3	3	3	3	2
	1	3	3	1	1	1
23	0	3	3	3	3	2
	1	3	3	1	3	2
24	0	3	3	3	3	3
	1	3	3	3	3	3
25	0	3	3	3	3	3
	1	3	2	3	3	3
26	0	3	3	3	3	2
	1	3	1	2	2	2
1 repeated score	0	3	3	3	3	3
	1	3	3	3	2	1
3 repeated score	0	3	3	3	2	2
	1	3	3	3	3	2

Table 18 Shows raw data for the assessment scores of tooth number 4

Participant Code	Tooth Type 0= Typodont 1= 3D image	Tooth Number	Access Score	Cavity Score	Deroofing	Pulp Ext
1	0	4	1	1	1	1
	1	4	3	2	1	1
2	0	4	1	1	3	3
	1	4	3	1	3	3
3	0	4	3	1	3	2
	1	4	1	1	3	3
4	0	4	2	1	1	1
	1	4	3	1	1	1
5	0	4	2	1	2	2
	1	4	2	1	3	3
6	0	4	2	1	2	1
	1	4	1	1	2	3
7	0	4	2	1	3	3
	1	4	3	1	3	3
8	0	4	3	1	3	3
	1	4	3	1	2	1
9	0	4	1	1	3	3
	1	4	2	1	3	3
10	0	4	3	1	3	3
	1	4	3	1	2	2
11	0	4	3	1	3	3
	1	4	2	1	3	3
12	0	4	3	1	3	1
	1	4	1	1	2	1
13	0	4	1	1	2	3
	1	4	2	1	2	1
14	0	4	2	1	3	3
	1	4	3	1	3	1
15	0	4	3	1	3	3
	1	4	2	1	2	3
16	0	4	3	1	3	3
	1	4	3	1	2	1
17	0	4	3	1	3	3
	1	4	3	1	3	1
18	0	4	1	1	3	1
	1	4	3	3	3	3
19	0	4	3	1	2	3
	1	4	1	3	3	3
20	0	4	1	1	1	1
	1	4	1	1	1	1
21	0	4	1	1	1	1
	1	4	1	1	1	1
22	0	4	1	1	3	3
	1	4	2	1	1	1
23	0	4	1	1	3	3
	1	4	2	1	3	3
24	0	4	3	1	2	1
	1	4	2	1	3	3
25	0	4	3	1	3	3
	1	4	3	1	3	3
26	0	4	3	1	3	3
	1	4	2	1	3	3
1 repeated score	0	4	2	2	1	1
	1	4	1	2	1	1
3 repeated score	0	4	1	3	2	3
	1	4	1	2	3	3

Table 19 shows raw data of the assessment scores of tooth number 5

Participant Code	Tooth Type 0= Typodont 1= 3D image	Tooth Number	Access Score	Cavity Score	Deroofing	Pulp Ext
1	0	5	1	1	1	1
	1	5	3	1	2	2
2	0	5	3	2	2	2
	1	5	3	2	2	2
3	0	5	3	2	2	2
	1	5	2	2	2	2
4	0	5	2	2	2	2
	1	5	3	2	2	2
5	0	5	1	2	2	2
	1	5	3	2	2	2
6	0	5	3	2	2	2
	1	5	3	2	2	2
7	0	5	2	2	2	2
	1	5	1	2	2	2
8	0	5	1	2	2	2
	1	5	2	2	2	2
9	0	5	1	2	2	2
	1	5	2	2	2	2
10	0	5	2	2	1	1
	1	5	2	2	1	1
11	0	5	2	2	2	2
	1	5	2	2	2	2
12	0	5	1	2	2	2
	1	5	2	2	2	2
13	0	5	3	3	2	2
	1	5	2	2	2	2
14	0	5	1	2	1	2
	1	5	3	2	2	2
15	0	5	3	3	1	1
	1	5	2	2	2	1
16	0	5	2	2	2	2
	1	5	3	2	2	2
17	0	5	3	2	2	2
	1	5	3	3	2	2
18	0	5	2	2	1	1
	1	5	1	1	3	3
19	0	5	1	2	1	1
	1	5	2	2	1	1
20	0	5	2	2	2	2
	1	5	2	2	2	2
21	0	5	3	2	2	2
	1	5	2	2	2	2
22	0	5	2	2	2	2
	1	5	2	2	2	2
23	0	5	2	2	2	2
	1	5	1	3	1	3
24	0	5	2	2	2	2
	1	5	2	2	2	2
25	0	5	3	2	2	2
	1	5	2	2	2	1
26	0	5	1	2	2	2
	1	5	2	2	2	2
1 repeated score	0	5	1	2	1	1
	1	5	2	2	1	2
3 repeated score	0	5	2	2	2	2
	1	5	2	2	2	2

4.8.1 Reliability of the participant assessment scores

Fleiss Kappa was run in SPSS version 26 to determine the agreement level of the participant's assessment scores of five typodont teeth and five 3D images. The kappa results obtained can be explained by Altman (1990) guidelines which are based on the value of Kappa (k):

- K value less than 0.20 = poor agreement
- K value 0.21-40 = fair agreement
- K value 0.41-60 = Moderate agreement
- K value 0.61-0.80 = Good agreement
- K value 0.81-1 = Very good agreement

The level of agreement of assessment scores of typodont teeth and 3D images are shown in *Table 20.* Using the Kappa classification, the results showed a fair level of agreement of the five typodont teeth assessment, k= 0.383 (95% CI, 0.382 to 0.384), p <0.0005. Kappa (κ) coefficient is statistically significantly different from zero. The five 3D image assessment results showed a fair level of agreement of the participants' scores, (Kappa) k= 0.326 (95% CI, 3.26 to 3.27), p<0.0005. There was a fair agreement of the participants' assessment for the total assessment of the Typodont and 3D images, (Kappa) k= 0.355 (95% CI, 0.354 to 0.355), p <0.0005. Kappa (κ) coefficient is statistically significantly different from zero.

Table 20 shows the level of agreement of the typodont and 3D images

	Overall Agreement of Typodont and 3D Image Assessment						
Assessment Type	n	Kappa	Asymptotic			Asymptotic 95% Confidence Interval	
			Standard Error	z	P Value	Lower Bound	Upper Bound
Typodont Assessment	26	0.383	0.009	40.900	0.000	0.382	0.384
3D Image Assessment	26	0.326	0.009	35.087	0.000	0.326	0.327
Typodont and 3D Image Assessment	26	0.355	0.007	53.755	0.000	0.354	0.355

Fleiss Kappa was also used to assess the reliability of each category of the assessment scores used in the study. *Table 21* shows the level of agreement of the typodont teeth assessment categories. Cavity outline assessment results showed a moderate level of agreement of the participants' assessments, (Kappa) k= 0.535 (95% CI, 0.534 to 0.536), p<0.0005. Access location results showed a poor level of agreement of the participants' assessments, (Kappa) k= 0.135 (95% CI, 0.134 to 0.136), p<0.0005. Pulp chamber removal results showed a fair level of agreement of the participants' assessments, (Kappa) k= 0.251 (95% CI, 0.250 to 0.252), p<0.0005. Pulp removal results showed a fair level of agreement of the participant's assessments, (Kappa) k= 0.266 (95% CI, 0.265 to 0.267), p<0.0005.

Table 21 shows the level of agreement typodont assessment criteria

	Typodont Teeth Assessment						
			Asymptotic			Asymptotic 95% Confidence Interval	
Assessment Criteria	n	Kappa	Standard Error	z	P Value	Lower Bound	Upper Bound
Cavity Outline and Size	26	0.535	0.016	32.509	0.000	0.534	0.536
Access Location	26	0.135	0.017	7.958	0.000	0.134	0.136
Pulp Chamber Removal	26	0.251	0.018	14.087	0.000	0.250	0.252
Pulp Removal	26	0.266	0.016	16.477	0.000	0.265	0.267

Table 22 demonstrates the level of agreement of the 3D image assessment categories. Cavity outline assessment results showed a moderate level of agreement of the participant's scores, (Kappa) k= 0.498 (95% CI, 0.497 to 0.499), p<0.0005. Access location results showed a poor level of agreement of the participant's assessments, (Kappa) k= 0.167 (95% CI, 0.166 to 0.168), p<0.0005. Pulp chamber removal results showed a fair level of agreement of the participant's assessments, (Kappa) k= 0.286 (95% CI, 0.285 to 0.287), p<0.0005. Pulp removal results showed a fair level of agreement of the participant's assessments, (Kappa) k= 0.257 (95% CI, 0.256 to 0.258), p<0.0005.

Table 22 shows the level of agreement of 3D image assessment criteria

	3D images Assessment						
			Asymptotic			Asymptotic 95% Confidence Interval	
Assessment Criteria	n	Kappa	Standard Error	z	P-Value	Lower Bound	Upper Bound
Cavity Outline and size	26	0.498	0.018	27.994	0.000	0.497	0.499
Access location	26	0.167	0.019	8.636	0.000	0.166	0.168
Pulp Chamber Removal	26	0.286	0.020	14.364	0.000	0.285	0.287
Pulp Removal	26	0.257	0.018	13.994	0.000	0.256	0.258

4.8.2 Difference between the typodont and 3D image assessments

Mixed model test analysis was used to assess the difference between the typodont teeth and the 3D image assessment. Cavity outline results showed a P-Value = 0.985 (95% CI, -0.922 to 0.906). Access location results showed a P-Value = 0.688 (95% CI, -0.653 to 0.453). Pulp chamber removal results displayed a P-Value = 0.953 (95% CI, -0.568 to 0.599). Finally, the pulp removal results stated a P-Value = 0.811 (95% CI, -0.448 to 0.556). The results show there isn't any statistical difference between the typodont teeth assessment and the 3D image assessments.

Table 23 Mixed analysis results of the assessment scores

	Mixed Analysis Results for Typodont Teeth and 3D image Assessment							
							95% Confidence Interval	
Assessment Criteria	n	Estimate	Std. Error	df	t	P-Value	Lower Bound	Upper Bound
Cavity Outline	26	-0.007692	0.396583	8	-0.019	0.985	-0.922214	0.906830
Access Location	26	-0.100000	0.239884	8	-0.417	0.688	-0.653174	0.453174
Pulp Chamber Removal	26	0.015385	0.253087	8	0.061	0.953	-0.568236	0.599005
Pulp Removal	26	0.053846	0.217775	8	0.247	0.811	-0.448344	0.556037

4.8.3 Intra-participant Reliability

Simple descriptive analysis was used to determine the intra-participant reliability analysis. Two of the participants repeated the typodont and the assessment of the 3D image. The results of participant 1 repeated scores showed consistency of 75% of the typodont teeth and 50% of the 3D image assessments. And participant 2's repeated scores showed an 85% consistency level for both the typodont and the 3D image assessment.

Chapter 5 Discussion (Main study)

This study aimed to design and validate an assessment system for pulpotomy dental procedures in paediatric dentistry. The preliminary study identified a routine paediatric dental procedure chosen by dental students. Pulpotomy was the procedure selected from the preliminary study. A scoring system was designed for a pulpotomy dental procedure, and five typodont teeth were prepared to reflect various levels of correct (and incorrect) clinical procedure. The prepared typodont teeth were scanned with CEREC Omnicam intraoral scanner and saved as a 3D image. Study participants were asked to assess both the physical (typodont) and digital teeth preparations. To prevent bias, the participants scored the five typodont teeth and five 3D images on two separate days.

This study aimed to evaluate the consistency between the typodont teeth assessments and the 3D images assessment. A mixed Model Test was used to analyse the data and detect the consistency between the typodont teeth and 3D image assessment. The results showed no statistical differences between the assessments of typodonts and the 3D images.

Fleiss Kappa analysis was carried out to obtain the agreement level of the typodont assessments. Also, a separate Fleiss kappa was obtained to assess the level of agreement for the 3D image assessments. The results showed a fair to moderate level of agreement in the typodont teeth assessment. Also, the assessments of the 3D image showed a fair to moderate level of agreement. Although the assessment scores were more consistent with a simple descriptive statistic, the Fleiss Kappa results showed a fair to moderate level of agreement. This is due to the wider range

of the assessment scores, which produces a lower level of agreement in the Fleiss Kappa results.

The literature mentioned various assessment methods used to evaluate dental student competencies in UK universities. These methods included competencies, logbooks, clinical totals, and paediatric case presentations. The assessment criteria for preclinical training with phantom head simulators in dental schools are not widely discussed in the literature and require further investigation (Grindrod et al., 2020). The current study designed a three-point assessment system with criteria specific to a pulpotomy dental procedure. The assessment grades consisted of good preparation, which scores 3, an acceptable preparation - score 2, and unacceptable preparation - score 1.

A study by Taylor et al. (2013) reported some reasons for the variations of dental student assessments scores. One of the reasons is that the assessors are hesitant to give a high score if a dental student carries out the preparation. An assessment system without a guide for the scores might be open to interpretation by the assessors, so the current study included a guide sheet including criterion in the assessment to help minimise the variability of the assessments.

The literature reported that assessors' calibration and limiting the rating scores produced more agreement between the assessment scores. So this study used only a scale of three scores to focus the scores on good, acceptable, and unacceptable (Haj-Ali and Feil, 2006). Limiting the assessment scale might produce a consistent score between the assessors compared to a larger scale. But the study aims to produce accurate

assessment scores of dental preparations, so a small assessment scale with descriptors is used in this study.

5.1 Intra-Participant reliability

Two participants (10% of the sample size) repeated the typodont and 3D image assessment to assess the intra-participant reliability. The results of the 1st participant's repeated scores showed consistency of 75% for the typodont teeth assessment and 50% for the 3D images assessment; and for the 2nd participant, the repeated scores showed an 85% consistency level for both the typodont and the 3D image assessments. The two participants who repeated the scores showed consistent scores when they repeated the typodont teeth assessment. At the same time, only one of the participants was consistent when scoring the 3D images. This may be due to the low number of repeated assessments used. Only 2 participants repeated their assessment scores once. The different scores in 3D images might be due to the staff's lack of the 3D image assessment experience for the participants, as the most common way of assessment is a visual assessment with typodont teeth.

The assessment system showed reliability in detecting an obvious error in the preparation. For example, in tooth number 4, 100% of the participants scored 1 as there is an over-extended access outline. Another example is in tooth number 5 on the pulp chamber roof removal criteria results, where 76% of the participants scored 2 as there is incomplete de-roofing of the pulp chamber. The participants showed high consistency in scoring when there was an obvious fault in the preparation. On the contrary, when there was an acceptable preparation, some participants showed inconsistent

scoring. In tooth number 2, the tooth had an acceptable access outline with no further adjustment required, but only 50% of the participants scored 3 for the access outline criteria. Also, in tooth number 3, the tooth has complete pulp removal, but the scores showed only 69% agreement of the participants' scores for the pulp removal criteria. Access location results showed a poor level of agreement of the participants' assessments on both the typodont and the 3D images assessments. This might be an indication of a wide range of the assessment scores of these criteria.

In a limited scoring system used in this study, a bad preparation might get a low score consistently. If the preparation has a subtle mistake, the student might be labelled as a bad performer and receive a bad score. On the other hand, the preparation has to be good to receive a high assessment score. In a wide-scale scoring assessment system, the assessor might be forced to narrow down their scoring, and the students will be less likely to receive a grossly bad score.

The assessment system results for the present study showed a high consistency level in detecting obvious errors in the dental preparations and less consistency when there were less obvious errors in the dental preparation. When there was an acceptable preparation, some participants judged the tooth as requiring further adjustments. It is better for an assessment system to have a few false negatives than false positives from a patient safety perspective. The assessment system won't score a bad preparation a high score and pass a bad performer student with a good score.

The preparation used in this study consisted of two acceptable preparations. Three typodont teeth preparations were carried out to cover all common errors a student might make in a pulpotomy preparation. Teeth number two and number three were prepared as acceptable preparation and required no further adjustments. However, some participants judged these two preparations as requiring further adjustments. This might be a weakness in the study design, as a certain number of clinicians would produce a different number of cavity designs which might be considered acceptable. Under preparation was carried out on tooth number one. Over preparation was carried out on tooth number four. Incomplete deroofing and incomplete pulp tissue removal were carried out on tooth number five of the typodont teeth. All preparation was approved by one of the supervisors of this study. The typodont teeth used in this study are shown in Figure 1.

5.2 Dental Student Assessment

The assessment system with descriptors used in this study is a useful method for providing feedback for students' preparations. It also provides an explanation for each score given. The results of an assessment system with descriptors may vary compared to a 2-point assessment system (Houpt and Kress, 1971).

A common type of assessment used to assess dental students is a traditional visual assessment with either a 2-point system (pass and fail) or an assessment with a detailed checklist system which is the type of assessment used in the present study. Using a checklist assessment, the study aimed to validate a scoring system for a routine paediatric dental procedure (pulpotomy). The scoring criteria were designed to be clinically

relevant with three categories (good, acceptable, and unacceptable). The assessment system consisted of four clinical criteria, each graded on a 3-point scale.

Accurate assessment methods are important for assessing dental students in preclinical education. The Checklist assessment scores varied compared to a 2-point scale when used to assess dental students. Still, a checklist assessment provides better feedback for dental students by providing a score for each criteria assessed (Goepferd and Kerber, 1980).

Dental simulation is commonly used in preclinical learning for dental students to develop their skills and practice routine dental procedures. The students can practice various dental procedures, including cavity preparation and dental crown preparation. Simulation based learning provides reliable hands-on experiences for the students in a controlled and safe learning environment (Perry et al., 2015). Traditional dental simulation may also improve preclinical teaching and reliability standardization with validated scoring systems for assessing clinical skills. Recently, digital assessment software (prepCheck and PrepAssistant) has been developed to assess routine dental procedures like cavity preparation and dental crown preparation. The computer software produces more consistent scores than the traditional visual assessment. But the traditional visual assessment provides more clinically relevant scores. The current digital assessment cannot be used alone to assess dental preparations. It provides an incomplete score when assessing dental crown preparation as it cannot assess the finish line and the smoothness of the preparation, which are important parameters for successful preparations (Cardoso et al., 2006).

This is consistent with the study results by Taylor et al. (2013). The study compared the assessment scores of two experienced clinicians of dental crown preparation on typodont teeth with a grade provided by PrepAssistant software. The study stated that the PrepAssistant could not be used on its own to assess students' preparations because the software cannot assess the finish line and surface smoothness of the dental crown preparation. As a result, the PrepAssistant could not provide a complete score while assessing dental crown preparation.

Nonetheless, various studies have explored the benefits of digital methods in dental students' preclinical teaching and assessment. They found that digital assessment software provides consistent assessment scores for dental preparations. Although PrepAssistant provides consistent scores compared to the traditional visual method, Taylor et al. (2013) found that it shouldn’t be used alone, so the present study used the clinical relevance of the traditional assessment method and included a digitized assessment method in the form of 3D images with scores provided by traditional visual assessment. To compare the similarities and differences in the assessments scores, digital assessment alone does not involve human involvement. This study used a computer screen for the 3D images to be assessed by the participants, and they didn’t have to collect the typodont teeth. Also, the participants could provide a comment if they noticed something on the 3D image assessment that wasn’t included in the traditional assessment. It appears from the results that the digitised images allowed assessors to give valid and reliable feedback. This suggests that students and teachers may not always need to work together at the same time as teachers could assess their work at a more convenient time.

Digital assessment methods complement the traditional assessment methods in assessing dental students' preparations. Although the digital assessment software doesn't provide a complete score of the preparation, it provides more consistent scores than the traditional assessment methods. Digital assessment methods might be used with the traditional methods to produce a consistent assessment score, which will benefit the dental student's learning and feedback during preclinical learning. So, this study used the traditional visual assessment method to assess five typodont teeth, and five digital 3D images (scanned images of the typodont teeth) were also assessed by a traditional visual assessment method. Similar evaluation forms were used for both the typodont teeth and the 3D images as the study aimed to see if a consistent score could be obtained from 3D images.

5.3 Covid-19 Pandemic

In March 2020, WHO declared Covid-19 a pandemic, which led to the moving to online teaching for schools and universities worldwide. This increased the value and the need to work and learn remotely or in a socially distant manner. The Covid-19 pandemic climate presented a challenge to deliver education for dental students, with dental schools increasingly needing distance learning and more opportunities for smaller groups of students to work in laboratories and clinics. Implementing validated assessment technology in preclinical dental education can benefit distant learning by allowing students to send scanned material to their tutors for assessment (Al-Taweel et al., 2021). In responding to the current status of the Covid 19 pandemic and its effects on education, there is a need for further research on distance learning and exploring the benefits of the

available 3D image assessments of dental students’ preparations. Physical digitization, which is scanning a physical object (typodont teeth) and saving it as a 3D image, might offer ease of assessing dental students' by sending the images to the teachers. This eliminates the need for staff to be present to evaluate the student's preparation and presents the need to validate reliable methods to evaluate the students’ preparations. The impact of the Covid-19 pandemic has affected the education of dental students, especially the dental students about to graduate and the newly graduated dentists. Final-year dental students had less clinical experience due to dental schools' inability to provide clinical experience for several months in 2020. This has led to the need for further development and training for newly graduated dentists.

Due to the Covid-19 impact on dental education, some newly graduating dentists in the United Kingdom have to undergo additional clinical assessments when starting the dental foundation training (Doughty and Moshkun, 2020). Validating 3D image assessments might benefit the dentist’s progression throughout their early years in practice. Newly graduated dentists could practice a dental procedure at their clinic on typodont teeth, scan it into a 3D image (Physical Digitization) and ask for an assessment and feedback remotely. With a continued move toward continued professional development within dentistry, a set of prepared typodont teeth can be sent to an expert in the field for feedback or assessment by Physical Digitization. At this time, the literature's main focus is comparing traditional visual assessment and digital assessment for dental students' dental crown and cavity preparation.

The inconsistent preclinical assessment might lead students to focus on the grades of their preparations instead of the actual learning process of the dental procedures. So, using a valid and reliable assessment system might produce a consistent assessments score and benefit the dental student’s education.

The literature has reported that assessing dental students with a scoring system with checklist criteria and staff members' training and calibration might minimize the inconsistent preclinical assessment of the dental students (Kateeb et al., 2017). This study used an assessments system with a detailed checklist for each criterion assessed which might aid the assessors in scoring the dental preparation and provide feedback for the dental students.

Undergraduate dental education has been explored in the literature in different dental specialties in the UK. These specialties include oral surgery, special care dentistry, and endodontics. There is a lack of information on paediatric dentistry teaching and assessments in UK dental schools (Grindrod et al., 2020). To obtain a 3D model of students' attempted dental preparation, one either can 3D scan the prepared typodont tooth (physical digitization) or have the students prepare a virtual tooth using a haptic simulator and export the 3D file produced.

5.4 Digital (3D) image assessment

The participants used the same assessment system to assess the typodont teeth and the 3D images. The study results showed no statistical differences between the typodont teeth assessment and the 3D images assessment.

The 3D image assessment can be advantageous in allowing staff of institutions in different countries to collaborate and work together. Also, the 3D image assessment allows more students and staff to work and request assessments remotely, which adds to the value of assessing the 3D image. A 3D image can be uploaded to a website, and the student can get several opinions from staff members who can access and assess the 3D image. Another factor is Covid-19 which presented the need for staff and students to work and interact remotely when possible, making the 3D images assessment beneficial if they are reliable. The substantial load of preclinical courses in most dental school programmes results in the student having little time to practice all the different dental preparations, at least within the normal day programme. Validating 3D image assessment will benefit as the students could potentially practice routine dental procedures out of routine hours and send the preparations as 3D images to tutors for evaluation and feedback at a convenient time. However, this also means that staffing would be required to supervise the dental students in the clinical skill lab (Gratton et al., 2017).

Validating an assessment system with a 3D image may help ease assessments and evaluate dental preparations by sending a 3D image to the dental specialists and experts for feedback. Also, 3D image assessment might help foundation dentists undergoing 12 months of training, with Covid-19 pandemic, which affected their dental training (Doughty and Moshkun, 2020).

The benefits of digital assessment include ease of access to many clinical tutors to assess and provide feedback for the student preparations and the

ability to view and zoom in on the digital image of the preparation to help view and assess the student's preparation consistently and reliably. The 3D image assessment provides an easy way of archiving and storing student work digitally, which gives value to the proposed digital assessment method.

The common methods for assessing dental students' preparations are the traditional direct visual assessment and the digital assessment software. The traditional assessment methods produce variable assessment scores. They are considered less consistent than the digital assessment software, but the traditional method provides more clinical assessment of the dental preparation. The traditional assessment is affected by the type of assessment used and whether it's a checklist or pass and fail assessment. Another factor is the range of the assessment scoring used. It is reported in the literature that the smaller the scoring range used, the more consistent the score is reported for the student assessment. Also, teacher calibration affects the assessment scores of both traditional and digital methods, which might minimize the variability of the assessment (Haj-Ali and Feil, 2006).

In the present study, the principal researcher briefly explained the assessment to the participants and used a three-point score for the assessment of the prepared teeth by both methods. The repeated scores of the 2nd participant showed high intra-participant reliability while the 1st participant had high reliability only in the typodont teeth assessment and only 50% reliability with the 3D images assessment. The examiners might be affected by the new experience of assessing a dental preparation in the form of a 3D image and might require more practice to produce consistent assessment scores. So, taking into consideration that only two participants

were used to assess intra-participant reliability, no significant difference was found between the two types of assessments used in this study.

The available digital assessment to date is computer software that provides an assessment score for a cavity or dental crown preparation, which isn't successful. The score provided is not a complete score that covers all the criteria of the preparations, it is difficult to put all the parameters into dental crown preparation, and it still requires a clinician to view, assess, and determine if it is a good preparation (Taylor et al., 2013). So, the evidence states that a tutor is better to assess these preparations than a computer as the digital assessment methods is limited in the score and feedback provided for the student preparations. A third way that hasn't been investigated previously is a tutor scoring a computerized image, which the participant (tutor) will score a 3D image, which derives the novelty of the research. The 3D images produced by scanning prepared typodont teeth by IOS and saved as a 3D image.

Clear feedback and reliable assessment methods should be used to successfully assess dental students on their performance in the preclinical stage. Designing and using suitable assessment methods may benefit effective teaching for the students. Also, calibration of assessors and using appropriate rating scales with detailed checklists for each criteria of the procedure assessed can be beneficial for the student's preclinical and clinical education and help the tutors provide more consistent feedback (Haj-Ali and Feil, 2006).

5.5 Study Limitation

There were difficulties in obtaining a larger sample size of participants as the teaching staff had very busy schedules during the pandemic and were partly working from home when not on clinical duties. Not all potential participants wished to take part in the study.

Some of the participants preferred to use only a numbering assessment system. The participants reported some difficulty using both wording and a numbering assessment to assess the prepared teeth and the 3D images.

5.6 Suggestions for future work

The results of this study did not find any significant differences between the assessment results of a pulpotomy using direct assessment of the typodont teeth or indirect assessment of the 3D images. Further research is required to evaluate the validity and reliability of the digital assessment system on a range of preparations carried out by dental students.

Some of the participants' feedback on the assessment system said that there should be either a wording or numbering score, as some of the participants reported difficulties in scoring the prepared teeth while trying to follow the guide of the assessment system. This suggests that further work is needed on how to improve instruction or training for staff on assessment criteria.

Chapter 6 Conclusion

From the study results, it can be concluded that the null hypothesis stating there would be no statistically significant difference between the assessment scores of the typodont teeth and the 3D images can be accepted. The assessment of 3D images of typodont teeth preparations can be a valid assessment method that can benefit students' education.

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List of Abbreviations

DOH	Department of Health
TEL	Technology Enhanced Learning
HPL	How People Learn
V.R.	Virtual Reality
OSCE	Objectively Structured Clinical Examination
VRDTS	Virtual Reality Dental Training System
CAD/CAM	Computer-assisted Design / Computer-assisted Manufacture
WHO	World Health Organization
3D	Three Dimensional
SSC	Stainless Steel Crowns
UG	Undergraduate
PG	Postgraduate
DREC	Dental Research Ethics Committee
HoD	Head of Department
IOS	Intraoral scanner

Appendices

Appendix 1

Questionnaire to assess the undergraduate student educational needs:

First Phase

1. How useful is phantom head exercises in paediatric dental procedure training?

   1 = Not useful. 10 = very useful. 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 -10

2. Do you feel preclinical training of different paediatric dental procedures prepared you for your first clinical experience?

   1 = Not well prepared. 10 = well prepared. 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 -10

3. How confident you were/ are to perform your 1st dental procedure on actual patient?

   1 = Not very confident. 10 = very confident. 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 -10

4. How confident are you on performing the following paediatric dental procedures

   1 = Not very confident. 10 = very confident.

   a. Pulpotomy 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 -10

   b. Stainless steel crown preparation 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 -10

   c. Caries removal and cavity preparation 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 -10

5. Would you welcome the opportunity for further preclinical training on paediatric dental procedures?

☐ Yes

☐ No

- If yes, please specify which of the following paediatric dental procedures, would you like further preclinical training on (you may choose more than one procedure):

  ☐ Pulpotomy

  ☐ Stainless steel crown preparation

  ☐ Caries removal and cavity preparation

Appendix 2

Questionnaire to assess postgraduate paediatric dental student educational needs:

First Phase

1. How useful is skill lab exercises in paediatric dental training?

   1 = Not useful. 10 = very useful. 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 -10

2. Do you feel skill lab training of different paediatric dental procedures prepared you to carry out treatment on actual patient?

   1 = Not well prepared. 10 = well prepared. 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 -10

3. How confident are you on performing the following paediatric dental procedures:

   1 = Not very confident. 10 = very confident.

   a. Pulpotomy 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 -10

   b. Stainless steel crown preparation 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 -10

   c. Caries removal and Cavity preparation 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 -10

4. Would you welcome the opportunity for further preclinical training on paediatric dental procedures?

☐ Yes

☐ No

- If yes, please specify which of the following paediatric dental procedures, would you welcome further preclinical training on (you may choose more than one procedure):

  ☐ Pulpotomy

  ☐ Stainless steel crown preparation

  ☐ Caries removal and Cavity preparation

Appendix 3

Participant Information Sheet

Questionnaire to assess the undergraduate student educational needs.

Dear Participant,

We would like to ask you to take part in the above named study. Before you decide to participate, please read the following information.

What is the purpose of this study?

This study aims to explore and investigate the student's perspective on their pre-clinical preparation and their level of confidence in carrying paediatric dental procedures, and whether they would welcome further pre-clinical training using dental haptic Simodont for routine paediatric dental procedures.

Who is doing the study?

This study is being carried out by a group of researchers in the paediatric department of the School of Dentistry. Dr. Aradhna Tugnait (Supervisor), Dr. Jinous Tahmassebi (Supervisor), Dr. Andrew Keeling (Supervisor) and Ms Cecilie Osnes (Supervisor). It is part of a Professional Doctorate degree by postgraduate student Abdullah Qali.

Why have I been asked to participate?

This research is student related, and cannot be undertaking unless you participate.

What will be involved if I take part in this study?

Participants will be asked to complete a paper copy of a questionnaire to evaluate their preclinical training on routine paediatric dental procedures. Also, the participants will be asked to rate their confidence in performing paediatric dental procedures and if they would like any further preclinical training on any paediatric dental procedures on the dental haptic Simodont.

What are the advantages and disadvantages of taking part?

Your involvement in this study might allow us to enhance dental education research, especially in the area of how best to educate dental students. The entire study will have no bearing on your practical examination marks and the project is independent of your academic studies and as such, participation is entirely voluntary.

Will I be paid for taking part?

No.

Can I withdraw from the study at any time?

No. You will not be able to withdraw after completing the questionnaire, due to the fact that the questionnaires are anonymised.

Will the information obtained in the study be confidential?

Any information collected during the course of this study will be anonymised will not be traceable to an individual. If information collected in this study is published in scientific journals, participants will be referred to by an anonymous code only. The terms of the data protection Act 1988 will be adhered to and information will be securely stored.

What will happen to the results of the study?

The results of the study will be analysed and published in a scientific peer reviewed journal.
The results of this study, as well as a copy of the final paper can be provided to you upon request. The data collected will be used in this study and, might be used in future studies.

Who has reviewed this study?

This study was reviewed and approved by the Dental Research Ethics Committee (DREC) the School of Ethics Committee, University of Leeds.

Ethical approval number (011019/AQ/286)

Ethical approval date (9.01.2020)

If you would like more information or have any questions or concerns about the study please contact: Abdullah Qali

Dr. Aradhna Tugnait
Associate Professor in Restorative Dentistry
Email: a.tugnait@leeds.ac.uk

Dr. Jinous Tahmassebi
Associate Professor in Paediatric Dentistry
Email: j.tahmassebi@leeds.ac.uk

Dr. Andrew Keeling
Clinical Associate Professor in Restorative Dentistry
Email: a.j.keeling@leeds.ac.uk

Ms. Cecilie Osnes
Research Assistant
Email: c.a.osnes@leeds.ac.uk

Dr. Abdullah Qali
PG Student School of Dentistry University of Leeds, LS2 9JT
Tel: 07463050633
Email: dnamha@leeds.ac.uk

Thank you for taking the time to read this and if you do decide to take part, we very much appreciate your involvement.

Appendix 4

CONSENT FORM

Questionnaire to assess the undergraduate student educational needs.

Name of Researchers:

Dr Jinous Tahmassebi, Dr Aradhna Tugnait, Dr Andrew Keeling, Miss Cecilie Osnes,

Dr. Abdullah Qali

Please write your initial in the box

1. I confirm that I have read and understand the information sheet dated 10/11/19 for the above study. I have had the opportunity to consider the information, and ask questions and have had these answered satisfactorily. ☐
2. I understand that my participation is voluntary. I have the right to refuse participation in the study. ☐
3. I will not be able to withdraw from the study after completing the questionnaire, as the questionnaires are anonymous. ☐
4. I understand that the data collected will be used in the current study and may be used in future studies. ☐
5. I agree to take part in the above study. ☐

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Name of student	Date	Signature
----------	----------	----------
Name of person taking consent	Date	Signature

Appendix 5

DREC ref: 011019/AQ/286 - Evaluating the use of dental haptic Simodont for paediatric dental education

Julie McDermott
Thu 09/01/2020 13:20

To: Abdullah Qali
Cc: Jianhua Wu; Jinous Tahmassebi; Aradhna Tugnait; Andrew Keeling

Dear Abdullah

DREC ref: 011019/AQ/286
Title: Evaluating the use of dental haptic Simodont for paediatric dental education

Thank you for submitting the amended documents for the above study. The documents have been reviewed and I am pleased to confirm that the study has been approved by the Dental Research Ethics Committee (DREC).

Documents reviewed

Document name	Version number and date
Ethics application form	Dated 11/12/2019
Protocol	Version 2 10/11/2019
Dental Haptics	Version 2 10/11/2019
Participant information sheet	Version 2 10/11/2019
Consent form	Version 2 10/11/2019
Questionnaire UG – phase 1	Version 2 10/11/2019
Questionnaire PG – phase 1	Version 2 10/11/2019
PowerPoint	Version 2 10/11/2019

With best wishes for the success of your project.

Please note: You are expected to keep a record of all your approved documentation, as well as documents such as sample consent forms, signed consent forms, participant information sheets and all other documents relating to the study, including risk assessments. This should be kept in your study file, and may be subject to an audit inspection. If your project is to be audited, you

Appendix 6

Instructions and Scoring Plastic Teeth

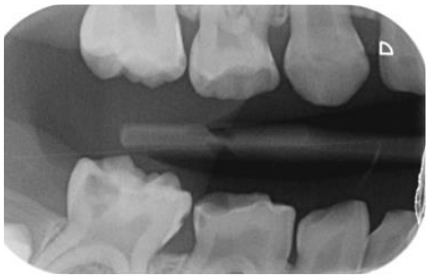
Participant Code: _____ Level: consultant/specialist/dentist Date: _____

Project title: Investigating the validity of a novel paediatric pulpotomy scoring system across typodont and digital 3D preparations.

Please review the clinical and radiographic information for the LRE (85). Then please provide grading for the five numbered plastic teeth preparations using the attached score sheet.

Clinical view

Bitewing radiograph



Marking System Guide

1. **Access/Cavity outline:**

3 = Appropriate access with no further adjustment required
2 = Under-extended access (Too small)
1 = Over-extended access (Too large)

2. **Access location:**

3 = Appropriate access site to pulp chamber
2 = Mild deviation of access site to pulp chamber
1 = Moderate/Severe deviation of access site to pulp chamber

3. **Pulp Chamber Roof removal:**

3 = Complete roof removal
2 = Incomplete de-roofing and/ Or (Gouging: Groove or indentation in walls by hand piece)
1 = Perforation

4. **Pulp removal:**

3 = Complete pulp removal - clear access to pulp orifice
2 = Incomplete pulp removal - inadequate access to pulp orifice
1 = Damage to pulpal floor

Note: the first plastic tooth depicts the damage caused by the caries

Pulpotomy 1	Good (3)	Acceptable (2)	Unacceptable (1)	Comments
Cavity outline and size				
Correct access location in regard of pulp chamber				
Pulp chamber roof removal				
Pulp removal				

Pulpotomy 2	Good (3)	Acceptable (2)	Unacceptable (1)	Comments
Cavity outline and size				
Correct access location in regard of pulp chamber				
Pulp chamber roof removal				
Pulp removal				

Pulpotomy 3	Good (3)	Acceptable (2)	Unacceptable (1)	Comments
Cavity outline and size				
Correct access location in regard of pulp chamber				
Pulp chamber roof removal Pulp removal				

Pulpotomy 4	Good (3)	Acceptable (2)	Unacceptable (1)	Comments
Cavity outline and size				
Correct access location in regard of pulp chamber				
Pulp chamber roof removal				
Pulp removal				

Pulpotomy 5	Good (3)	Acceptable (2)	Unacceptable (1)	Comments
Cavity outline and size				
Correct access location in regard of pulp chamber				
Pulp chamber roof removal				
Pulp removal				

Instructions and Scoring Scanned 3D Images

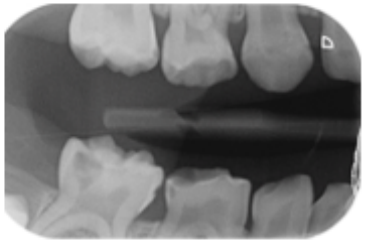
Participant Code: _____ Level: consultant/specialist/dentist Date: _____

Project title: Investigating the validity of a novel paediatric pulpotomy scoring system across typodont and digital 3D preparations

Please review the clinical and radiographic information for the LRE (85). Then please provide grading for the five numbered scanned 3D Images on attached score sheet.

Clinical view

Bitewing radiograph



Marking System Guide

1. **Access outline:**

3 = Appropriate access with no further adjustment required
2 = Under-extended access (Too small)
1 = Over-extended access (Too large)

2. **Access location:**

3 = Appropriate access site to pulp chamber
2 = Mild deviation of access site to pulp chamber
1 = Moderate/Severe deviation of access site to pulp chamber

3. **Pulp Chamber Roof removal:**

3 = Complete roof removal
2 = Incomplete de-roofing and/ Or (Gouging: Groove or indentation in walls by hand piece)
1 = Perforation

4. **Pulp removal:**

3 = Complete pulp removal - clear access to pulp orifice
2 = Incomplete pulp removal - inadequate access to pulp orifice
1 = Damage to pulpal floor

The 3D Image can be opened, for example, through a program called MeshLab, which allows you to view the image from all directions also, the Digital Teeth can be rotated and tipped to allow assessment of the preparation.

Pulpotomy 1	Good (3)	Acceptable (2)	Unacceptable (1)	Comments
Cavity outline and size				
Correct access location in regard of pulp chamber				
Pulp chamber roof removal				
Pulp removal				

Pulpotomy 2	Good (3)	Acceptable (2)	Unacceptable (1)	Comments
Cavity outline and size				
Correct access location in regard of pulp chamber				
Pulp chamber roof removal				
Pulp removal				

Pulpotomy 3	Good (3)	Acceptable (2)	Unacceptable (1)	Comments
Cavity outline and size				
Correct access location in regard of pulp chamber				
Pulp chamber roof removal				
Pulp removal				

Pulpotomy 4	Good (3)	Acceptable (2)	Unacceptable (1)	Comments
Cavity outline and size				
Correct access location in regard of pulp chamber				
Pulp chamber roof removal				
Pulp removal				

Pulpotomy 5	Good (3)	Acceptable (2)	Unacceptable (1)	Comments
Cavity outline and size				
Correct access location in regard of pulp chamber				
Pulp chamber roof removal				
Pulp removal				

Appendix 7

Version 5 21/1/2021

Participant Information Sheet

Investigating the validity of a novel paediatric pulpotomy scoring system across typodont and digital 3D preparations

We are inviting you to take part in the above-named study. Before you decide to participate, please read the following information.

What is the purpose of this study?

This study aims to explore and validate a standardised scoring system for a routine paediatric dental procedure (primary tooth pulpotomy) carried out on a plastic tooth in a phantom head simulator. Participants will also be asked to score scanned 3D images (Digital Teeth) of the preparations to determine if the scoring is the same or different when the Digital Teeth can be rotated and tipped to allow assessment of the preparation. The study also aims to evaluate if the scoring is uniform among consultants and clinical staff who teach undergraduate dental students.

Who is doing the study?

This study is being carried out by Abdullah Qali as part of the requirements for the DPaed Dent degree. His supervisors are: Dr. Aradhna Tugnait, Prof Bernadette Drummond, Dr. Andrew Keeling, and Dr Cecilie Osnes.

Why have I been asked to participate?

We are aiming to recruit consultants and clinical staff who teach undergraduate dental students in Paediatric Dentistry.

What will be involved if I take part in this study?

You will be asked to evaluate five plastic teeth with pulpotomy preparations and five images of the same teeth using a scoring system designed by Mr. Qali. There are two assessments, one is assessing plastic teeth as used in dental simulation by dental students and, the other is assessing scanned 3D images (five images) of the same teeth and preparations.
The plastic teeth assessment can be taken at your desk and, you will be able to access the digital image on your computer for assessment. The same scoring system will be used each time.
The scoring system will take no more than 30 minutes to be complete to score five plastic teeth and five digital images, which will be carried out on two separate days within a week. You will be randomised in the order of the assessment to prevent bias. Also, 10% of all scoring will be repeated to assess the reliability of the scoring among the participants.

What are the advantages and disadvantages of taking part?

The advantages of this study are that your involvement will allow us to assess and validate the scoring system and evaluate the results across consultants and clinical staff with different levels of experience. We will also assess if there are any differences between the evaluation of the plastic teeth preparations and the scanned 3D images. The results of this study can help to enhance dental student education by confirming the reliability of a scoring system to be used during simulation. There are no perceived disadvantages in participating in the study.

Will I be paid for taking part?

No financial rewards will be provided in this study. We shall provide a summary of the results for all participants.

Can I withdraw from the study at any time?

You may withdraw from the study at any time. You can contact a member of the research team to request that you be withdrawn and your data destroyed. All related information will be discarded and will not be used in data analysis. If you wish to withdraw after the data has been collected and analysed the anonymised data will remain in the study.

Will the information obtained in the study be confidential?

Any information collected during the course of this study that can be traced back to you will remain strictly confidential. Analysis will only occur on anonymised data. Published information will not use any reference to participants and all data will be anonymised. The anonymised data collected may also be used in future studies. The terms of the data protection Act 2018 will be adhered to and information will be securely stored in the University of Leeds on a secure server.

What will happen to the results of the study?

The results of the study will be analysed and published in Mr Qali's thesis and may be submitted to a scientific peer reviewed journal and presented at a dental meeting.

Who has reviewed this study?

This study has been reviewed by The Dental Research Ethics Committee (DREC) the School of Ethics Committee, University of Leeds.

Ethical approval number (301120/AQ/311)

Ethical approval date (22/02/2021)

If you would like more information or have any questions or concerns about the study please contact: Abdullah Qali

Dr. Aradhna Tugnait
Associate Professor in Restorative Dentistry
Email: a.tugnait@leeds.ac.uk

Prof. Bernadette Drummond
Clinical Professor in Paediatric Dentistry
Email: B.K.Drummond@leeds.ac.uk

Dr. Andrew Keeling
Clinical Associate Professor in Restorative Dentistry
Email: a.j.keeling@leeds.ac.uk

Ms. Cecilie Osnes
Research Assistant
Email: c.a.osnes@leeds.ac.uk

Dr. Abdullah Qali
PG Student Paediatric Dentistry
School of Dentistry, University of Leeds LS2 9LU
Email: dnamha@leeds.ac.uk

Thank you for taking the time to read this and if you do decide to take part, we very much appreciate your involvement.

Appendix 8

CONSENT FORM

Project title: Investigating the validity of a novel paediatric pulpotomy scoring system across typodont and digital 3D preparations

Name of Researchers:

Dr. Aradhna Tugnait, Prof Bernadette Drummond, Dr. Andrew Keeling, Miss Cecilie Osnes, Dr. Abdullah Qali

Please write your initial in the box

I confirm I have read and understand the information sheet dated 21/01/2021 for the above study. I have had the opportunity to consider the information, and ask questions and have had these answered satisfactorily. ☐

1. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason also. ☐
2. I understand that the data collected will be used in the current study. ☐
3. I agree to take part in the above study. ☐

---------- ----------

Name of Consultant/ staff member Date

Appendix 9

DREC ref: 301120/AQ/311

Julie McDermott
Tue 23/02/2021 14:17
To: Abdullah Qali
Cc: David Wood; Andrew Keeling; Aradhna Tugnait; Bernadette Drummond

Dear Abdullah

DREF ref: 301120/AQ/311
Study title: Investigating the validity of a novel paediatric pulpotomy scoring system across typodont and digital 3D preparations

Thank you for re-submitting the amended documents for the above study. The documents have been reviewed and I am pleased to inform you that the application has been approved by the Dental Research Ethics Committee (DREC).

Documents reviewed

Document name	Version number/date
Ethics application form	Dated 22/02/2021
Protocol	Version 5 21/01/2021
Participant information sheet	Version 5 21/01/2021
Consent form	Version 5 22/12/2020
Instructions and scoring sheet	Version 4 24/11/2020

With best wishes for the success of your project.

Please note: You are expected to keep a record of all your approved documentation, as well as documents such as sample consent forms, signed consent forms, participant information sheets and all other documents relating to the study, including risk assessments. This should be kept in your study file, and may be subject to an audit inspection. If your project is to be audited, you will be given at least 2 weeks' notice.
It is our policy to remind everyone that it is your responsibility to comply with Health and Safety, Data Protection and any other legal and/or professional guidelines there may be.

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