TRADITIONAL AND DIGITAL ASSESSMENT OF A PROTECTIVE MATRIX TO MINIMIZE IATROGENIC DAMAGE OF ADJACENT TEETH DURING CROWN PREPARATION BY DENTAL STUDENTS

By

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES

(Craniofacial Science)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

August 2019

The following individuals certify that they have read, and recommend to the Faculty of Graduate and Postdoctoral Studies for acceptance, a thesis/dissertation entitled:

Traditional and digital assessment of a protective matrix to minimize iatrogenic damage of adjacent teeth during crown preparation by dental students

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Abstract

Crown preparation is a challenging procedure for dental students, especially in the posterior region. It has been reported that the incidence of iatrogenic damage to adjacent teeth is very high during conventional crown preparation.

Objectives: To determine the effect of using a protective matrix for preventing iatrogenic damage to adjacent teeth during crown preparation on typodont teeth by undergraduate dental students.

Methods: 60 undergraduate students, in their second-year, volunteered for this study as part of their formal learning to prepare the mandibular first molar for a full-metal crown restoration on a manikin-mounted typodont. The study was divided into three parts: Part I- students were randomly assigned into two groups to either undertake tooth preparation according to a traditional crown preparation protocol, or tooth preparation using a protective matrix, followed by Part II- a crossover of the groups in the subsequent session. Part III - subsequent to the initial sessions, the students undertook a usual timed crown preparation exercise, during which using the matrix was optional. Damage to the adjacent teeth was evaluated subjectively by calibrated faculty members both using a standard traditional approach and virtual-assisted using a digital system. Depth and volumetric measures of the damage were also objectively evaluated using a digital system.

Results: During the practice sessions, the traditional subjective assessment found that adjacent tooth iatrogenic damage was significantly (p=.027) less frequent when the protective matrix was used, 76.9%, compared to when it was not used, 92.5%. A similar statistically significant (p=.009) pattern was found with the subjective virtual-assisted digital assessment, which showed a frequency of 82.4% when using the matrix compared to 98% when it was not used. The objective digital assessment tended to show a higher overall frequency of damage than that found with the subjective faculty-member assessments. During the two combined initial sessions the mean depth scores were 0.281±0.14mm without a protective matrix and 0.216±0.13mm with a protective matrix, which was significantly deeper iatrogenic depth damage ($p = .041$) without the matrix.

Conclusions: The use of a protective matrix during typodont crown preparation by dental students reduced the frequency of iatrogenic damage to adjacent teeth.

Lay Summary

In the first two years of dental training, students practice in a preclinical setting on a manikin head with plastic teeth to gain the necessary knowledge and technical skills needed to be able to treat live patients. It has been reported that the incidence of damage to adjacent teeth during tooth preparation is high. In this study, a comparison was made in students' performance using a protective device with a thin steel barrier to prevent damage to adjacent teeth during crown preparation versus performing the preparation without the protective device. Use of the protective device reduced the frequency and severity of damage to adjacent teeth during preclinical crown preparation.

Preface

All aspects of this project, including research design, sample preparation, virtual assessment of the samples, digital scanning of the samples, statistical analysis and dissertation writing, were accomplished under direct supervision of Dr. Ross Bryant, from the Faculty of Dentistry who provided constant guidance and expertise. The research committee members were Dr. Christopher Wyatt and Dr. Vincent Lee from the Faculty of Dentistry.

I supervised the volumetric measurement of the damage performed by Paul Ro Dental Laboratory, and I did all subsequent data collection, measurements, and analysis independently.

Ethical approval was required for this educational research study as students were involved and was granted by the UBC Behavioural Research Ethics Board, Vancouver, BC, Canada (reference number: H17-02108).

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List of Abbreviations

ANOVA	Analysis of Variance
CAD	Computer Aided Design
CAM	Computer-Aided Manufacturing
DMD	Doctor of Dental Medicine
FDP	Fixed dental prostheses
3D	Three-Dimensional
IOS	Intraoral Scanners
mm	Millimeter
µm	Micro-meter
SEM	Scanning Electron Microscope
STL	Standard Tessellation Language
SQ	Satisfaction Questionnaire
UBC	University of British Columbia

Acknowledgements

I would like to take this opportunity to express my heartfelt gratitude to all those who helped me to make my thesis work a success. First, I would like to express my deep sense of gratitude to Dr. Ross Bryant for his valuable guidance, contribution, and keen interest and encouragement at various stages of my training period. It was a great learning experience under his supervision included an emphasis on developing collaborative relationships with peers, and the ability to work both independently as well as part of a team.

Besides my supervisor, I offer my most sincere appreciation to my committee members: Dr. Christopher Wyatt and Dr. Vincent Lee for their time and efforts in providing me with their constructive feedback.

I would like to express my sincere thanks to Dr. Mathias Schede for his assistance with traditional subjective assessment, and Dr. Jolanta Aleksejuniene for her assistance with statistical analysis and advice.

Finally, I would like to thank Jae Won Sim, the digital expert and industrial designer at Paul Ro Dental Laboratory for his helpful advice on technical issues and CAD/CAM designing in this work.

Special thanks are owed to my family, who have supported me throughout my years of education.

Dedication

I would like to dedicate this master's thesis to

My dear wife Yasmin, and my lovely children, Mansour, Samiha, Muhammad, and Yousuf who joined me during the whole process and helped me in every way with their love, support and patience.

My beloved parents (Mansour and Samiha), who always inspired me and gave me the strength throughout my entire life.

Chapter 1: Introduction and Review of Literature

1.1 Statement of the Problem and Rationale of the Study

Preparation of a structurally weak tooth for fixed restoration with a full crown, essentially covering all of the exposed surfaces of the tooth, is a common procedure in clinical dental practice to improve durability of the tooth. To afford adequate mechanical, biological and aesthetic outcomes,[1-4] the preparation procedure should follow certain principles aiming for specific geometrical features or elements in the prepared tooth to provide the necessary retention and resistance form to withstand vertical and lateral forces acting to dislodge the crown restoration, and to provide enough reduction depth for adequate structural integrity of the artificial crown. Artificial crowns are made indirectly outside the mouth and need to follow a single path of insertion usually from the occlusal direction, meaning the axial walls of the tooth preparation must taper with a slight convergence from the gingival to the occlusal aspect. Tooth preparation principles also mandate minimizing reduction depth to help preserve healthy dentin, pulp, and periodontal tissues of the tooth being prepared while not damaging the structure of adjacent teeth, which are frequently in direct contact at the mesial and/or distal proximal surfaces of the tooth prior to the crown preparation. Traditional techniques emphasize that the most important geometrical element for retention of an artificial crown is the presence of nearly vertical opposing axial surfaces for the crown preparation circumferentially, such that the axial walls converge occlusally with approximately 6 to 10 degrees of taper overall. Adequate structural integrity and preservation of tooth structure targets an axial preparation depth just sufficient for the restorative material, optimally 0.5 mm at the cavosurface margin of a full metal crown. Overall, the tooth reduction for an artificial crown restoration should aim to balance the preservation of healthy structures with the need to create an optimal margin width and axial tapering to achieve the desired aesthetics, strength, and passivity of the definitive restoration.[1] The problem is that safe reduction of the proximal surfaces, especially in the posterior region, is a challenging procedure, especially for both dental students and inexperienced dentists because of the need to control the bur precisely for reduction depth and taper despite limited visibility, and without contacting adjacent teeth, which are in very close proximity to the tooth being prepared.

Consequently, the proximal reduction part of the procedure is usually performed with narrow needle-shaped burs intended to avoid damaging the adjacent teeth. The more parallel the proximal surfaces in the preparation, the greater the retention. However, due to the difficulty of preparing parallel surfaces without creating undercuts relative to the path of insertion of the restoration, or accidentally damaging the adjacent teeth,[5] Goodacre and his coauthors suggest an angle of convergence between 10 and 20° for the proximal surfaces,[2] and not exceeding 20 degrees as this would negatively impact retention of the crown.[6]

Furthermore, compelling evidence suggests that the incidence of iatrogenic damage to adjacent teeth is very high during approximal preparation with conventional instrumentation and methods. Several studies on crown and class II preparation report rates of damage to the adjacent teeth as high as 74-100%, even among experienced clinicians.[7-10] Overall, the frequency and extent of damage seem to depend on several factors, including the clinical circumstances and the clinicians' levels of skill and experience.[11] Damaging the enamel of the adjacent teeth will result in surface roughness or grooves that lead to plaque accumulation or increased permeability to acid, especially in deep grooves; such damage increases susceptibility to caries and periodontal disease.[12,13] To avoid this problem, students early in their learning process may tilt the bur, which can over-taper and over-reduce the crown preparation. This over-correction compromises the retention of the definitive restoration and/or unnecessarily weakens the tooth structure and compromises the pulp vitality. Over-tapering and over-reduction of the proximal surface are common mistakes because of the inherent difficulty involved in the preparation and the subjectivity of inexperienced clinicians' judgment.[5] Controlling and assessing the amount of tooth reduction can be achieved by using reference (depth) grooves or potholes prepared initially on the tooth surface, and by using a matrix (e.g., a vacuum formed clear matrix or a reduction jig made with putty as a reduction guide to indicate the contour of the final artificial crown. However, these methods cannot help much, if at all, to guide reduction at the proximal axial surfaces because of the close proximity of the adjacent teeth.

Overall then, proximal surface reduction of a crown preparation, especially in the posterior region, is a challenging procedure, especially for novice dental students because of the need to control the bur precisely to achieve accurate tapering and small axial reduction depths without iatrogenic damage to adjacent teeth, which, as noted, are in very close proximity to the tooth being prepared.

Complicating any investigation of this problem are two additional problems. Investigating the methods of evaluating damage to adjacent teeth created during crown preparation with a rotary instrument has not yet been sufficiently examined in the literature, despite advances in the use of digital scanning technology which could assist in the three- dimensional (3D) imaging of dental surfaces. Secondly, there has been inadequate study of the effectiveness of preventative approaches to minimize the damage of adjacent teeth during crown preparation. However, a new generation of dental wedges offer a novel protective aid for use during proximal tooth preparation including the FenderWedge® (Upplands Väsby, Sweden) designed with a protective stainless-steel matrix attached to a plastic wedge to secure the matrix in place during preparation.[8]

Therefore, this thesis research was designed to investigate students' performance in proximal wall reduction during crown preparation in a preclinical setting, specifically implementing the use of a protective matrix for reducing iatrogenic damage to adjacent teeth and the use of digital technology to assist evaluation of the damage.

1.2 Preclinical Teaching in Fixed Prosthodontics

Undergraduate education for dental students requires both theoretical and practical training initially in a preclinical, simulated environment. The preclinical training phase allows students to gain knowledge, skills and attitudes, especially development of manual fine motor skills, needed to apply tooth preparation procedures in the challenging phase of clinical patient care.[14]

Although the introduction of preclinical simulation in dental education was originally driven by patient safety,[15,16] other educational features of simulation soon became apparent. For example, the simulation phase can enhance students' confidence in preparation for their transfer to clinical patient treatment. [15,17] Simulation experiences also reduce the cognitive load for students by simplifying the complex process of learning fine motor skills,[18] along with providing opportunities for standardized learning and assessment.[19]

In North American dental schools, simulation training is mostly provided over the first two years of the dental curriculum, which allows novice students to develop the psychomotor skills needed to succeed with the challenges posed in their subsequent clinical experiences across several surgical disciplines in dentistry, including fixed prosthodontics. Fixed prosthodontics is commonly referred to as the branch of prosthodontics concerned with the replacement and/or restoration of teeth by a fixed dental prosthesis that cannot be removed from the mouth by the patient.[20] In fixed prosthodontics psychomotor skills training is usually achieved by preclinical training on manikin heads, which provide an efficient way to teach students tooth preparation procedures safely.[16,21] The manikin head is attached to a dental operating unit, in some cases with a manikin torso, in a manner that allows adjustment of the operating position to permit the students to work in a seated position similar to a clinical setting.[16] These manikin heads are scrupulously designed, ranging from a simple design with rubber cheeks and an adjustable mouth opening, to more complex design that includes a high-grade simulator with various occlusal and jaw movement functions. The latter design provides optimum realism in helping to replicate the real-life clinical environment.[21] To mimic a clinical setting and for student safety, students perform dental procedures wearing standard personal clinical attire (gowns, face masks, and gloves) and use rotary dental hand-pieces with water spray, as a concomitant coolant and rinse, and suction lines for water evacuation.[16]

For novice dental students to perform extremely precise dental surgical procedures in a preclinical setting, they must be able to learn very fine motor control and maintain excellent hand-eye coordination.[14] Motor learning involves improvements in the performer's capability to coordinate their grasp and to manipulate both their hand and the rotary instrument to achieve a desired task.[22,23]

The stages of motor learning can be divided into early learning stages: the "cognitive stage" and the "associative stage", and the late stage of learning, called the "autonomous stage".[24,25] The cognitive stage is characterized by inconsistency, inaccuracy, and a lack of confidence.[25] In this stage, the novice learner considers the preclinical activities mainly cognitively to determine appropriate motor skill strategies. Good strategies, through the trial-and-error of learning tasks, are retained, and ineffective strategies are rejected.[23,26] In the associative stage, the learner has determined more effective ways to perform the task and begins to refine his/her performance. The skills in this stage improve gradually and become more consistent, fluent, and efficient.[22] During the final, autonomous stage of learning, motor skills have become mostly automatic. Progression to this level may take a long time, even after significant and repeated experiences of practice, however, it indicates the learner is able to perform the task with very little cognitive involvement compared with the early learning stages.[25]

In 1993, Chambers used motor skills theory to describe competence based on learning related education, which is defined as "the behaviour expected of the qualified beginner."[27] Clinical teaching in dental education uses assessment techniques and decisions that match the stages along this competency continuum (Figure 1). Chambers argued that novices are evaluated with didactic and simulation tests, while beginners after acquiring initial motor skills and clinical judgment are evaluated with an assessment in direct patient care. Subsequently graduation of students signifies their competency to continue learning independently.[27]

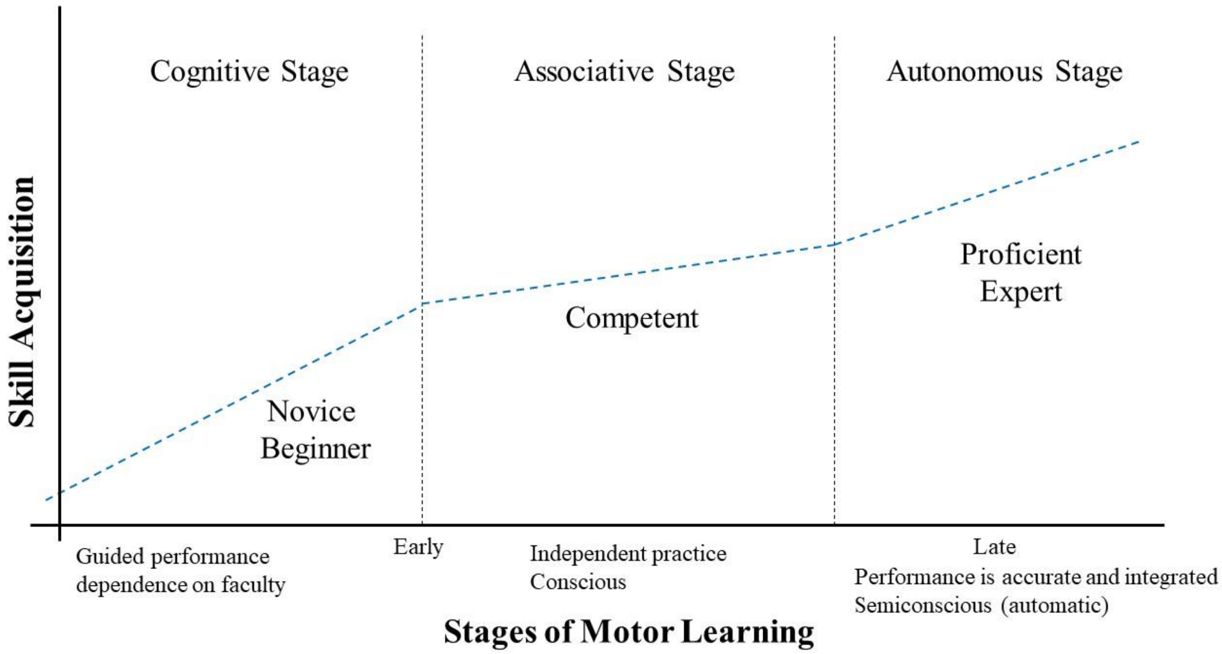

Figure 1. Adapted from Chambers[27] stages of motor learning and competency.

1.3 Tooth Preparation and Iatrogenic Damage of Adjacent Teeth

Tooth preparation, which is a basic aspect of the treatment of dental hard tissue in fixed prosthodontics and other dental surgical sciences, is the process used for the quantitative preparation of tooth tissues and the construction of a fixed dental prosthesis, either as an individual crown or as a crown retainer for a fixed dental prosthesis, which acts as an anchor to attach an artificial tooth as a pontic to replace a missing tooth. As noted, this procedure should be performed according to established scientific principles leading to satisfactory mechanical, biological and aesthetic outcomes.[1-4] At present, tooth preparation is generally performed with a high-speed rotary instrument, using a built-in water-cooling system. Safe and effective use of these instruments depend on the accuracy of the operator's vision and spatial interpretation abilities in three dimensions, and his/her hand skill abilities to control instrument movements in the narrow confines of the oral cavity.

Achieving high standards for attaining the essential geometrical features of a crown preparation, such as accurate tapering and convergence angles and small axial reduction depths, is a challenging task for novice dental students. The task is especially difficult when preparing a posterior tooth. As a result, teeth are frequently either overprepared or underprepared (Figure 2) in the early learning stages, which can unnecessarily sacrifice retention and resistance for the crown and/or impair restoration quality or tooth health. Under preparation can lead to insufficient restoration space, which results either in poor strength of the crown veneer material or in over contouring of the artificial crown, especially in the cervical third of the restoration, which can be detrimental to oral hygiene and periodontal health. To the best of my knowledge, there is no investigation of the viability of simultaneously achieving the essential geometrical aims of crown preparation in the proximal region (optimal tapering, minimum reduction and avoidance of damage to the adjacent tooth) while the tooth is still in contact with the adjacent teeth.

There is clear evidence of iatrogenic damage during dental restorative procedures. Indeed past literature has reported that iatrogenic damage to adjacent teeth is almost unavoidable during conventional class II cavity and full crown preparations, despite the widespread persistence of teaching standards on completely avoiding such damage.[7-9,11,28] However, most of these studies unexpectedly have investigated the damage of adjacent teeth during class II cavity preparation,[8,11,28] and only two studies investigated damage during crown preparation.[7,9] This was not expected because the method used to capture damage of the adjacent teeth was mainly an elastomeric impression, which is traditionally a routine part of crown procedures although it is not usually needed for restoring class II preparations.

Evaluation of the damage of adjacent teeth created during crown preparation with a rotary instrument has not yet been sufficiently examined in the literature. Furthermore, there has been an inadequate study of the effectiveness of preventative approaches to minimize the damage of the adjacent teeth during crown preparation. Moopnar and Faulkner [9] were among the earliest examiners who clinically investigated the incidence and extent of iatrogenic damage to teeth adjacent to crown preparations made as prosthetic abutments. The inclusion criteria of their study were a tooth preparation that had at least one adjacent tooth surface. The crown preparations were undertaken by undergraduate dental students, postgraduate residents, and experienced dentists. The investigators used dental stone working casts of full arches, including the crown preparations reproduced with elastomeric impressions. An overall number of 370 casts with 652 adjacent proximal surfaces were inspected. The incidence of surface damage was found to be 73.8% among the 652 surfaces, which is evidently very high.[9] Interestingly, most of the damage was done by experienced dentists, as out of 652 surfaces examined, only 18 surfaces were from undergraduate student cases.

Abdulwahhab and his coauthor [7] recently published a study that investigated the degree and frequency of iatrogenic damage to teeth adjacent to abutments prepared by undergraduate dental students. Among the 111 casts that were inspected, the incidence of surface damage was found to be as high as 98.2%. The authors classified the type of damage into three categories: nicks (grooves in the long axis of the tooth presumably caused by the tip of the bur digging into the enamel), abrasions (areas where a large surface had been removed without causing grooves), and both nicks and abrasions. The most common type of damage was abrasion more than 0.1 mm in depth (58.7%). The most commonly damaged area was the middle third of the proximal surface, and was more frequent in maxillary teeth (60.4%), than in mandibular teeth (39.6%).

These studies highlight the need for greater consideration of proximal tooth surfaces during crown preparation and awareness of the potential for iatrogenic damage.[7,9]

1.4 Consequences of Iatrogenic Damage

Tooth surfaces adjacent to dental restorations show a higher chance of caries,[12] which raises the question about the likelihood that iatrogenic preparation damage may add to the risk of further harm of these surfaces. Unless the adjacent surface was previously restored, this damage almost certainly occurs substantially in the enamel surface structure. Enamel is the hardest substance in the human body, and as such contributes a natural resistance to tooth wear and dental caries. However, the enamel can vary in thickness and hardness on each tooth, from tooth to tooth, and from person to person,[29] so the consequence of iatrogenic damage is essentially also uncertain in any one individual.

Nonetheless, the consequences of accidental damage of adjacent teeth is likely related somewhat to its severity and/or extent. Although this was not well-quantified in published literature, the depth severity of such iatrogenic damage ranges from broad surface roughness to deeper scratches, furrows, grooves, or other extensive damage that may cause alterations in the shape of the surface (Figure 3).[9] Based on the severity and extent of the defects, damaging the external surface of the enamel of the adjacent teeth as deep as 120 µm results in increased permeability to acid-like substances and consequent susceptibility to caries.[13] In addition, plaque accumulation associated with tooth surface roughness, regardless of the procedure that caused the roughness, may also increase caries susceptibility.[30]

Interdental stripping of proximal tooth surfaces, even up to 500 µm depth for anterior teeth, is a procedure occasionally used in orthodontics to create space in cases of mild or moderate crowding by interproximal enamel reduction. Polishing of the reduced enamel surfaces should decrease but not totally eliminate the surface irregularities.[31] Under such circumstances, increased plaque accumulation could be expected because even intensive hygiene cannot remove plaque from these grooves in the enamel surface.[30,31]

The initial tooth reduction in a conventional technique of crown preparation is usually performed with a coarse diamond bur, which will substantially roughen the enamel surface even if it only lightly touches the adjacent tooth. This roughness is not likely to be smoothed later if the operator is not aware of this slight defect.

In recent years, more information has been released on the increasing risk for both caries and periodontal inflammation due to a concurrent increase in plaque accumulation when the surface roughness increases by more than a 0.2 µm.[32] An in vitro study by Aykent and his coworkers investigated the effect of different surface finishing and polishing methods on bacteria adhesion, showing a higher vital bacterial adhesion on surfaces finished with a diamond rotary cutting instrument due to the surface roughness.[33]

Polishing minor damage to adjacent surfaces and applying topical fluoride subsequently is recommended.[34] However, attempts to finish and polish more severe damage to enamel surfaces may also be detrimental to the proximal tooth contours, proper proximal contact and the space and support needed for healthy gingival tissue. In such cases restoring the severely damaged surface would be recommended.[9]

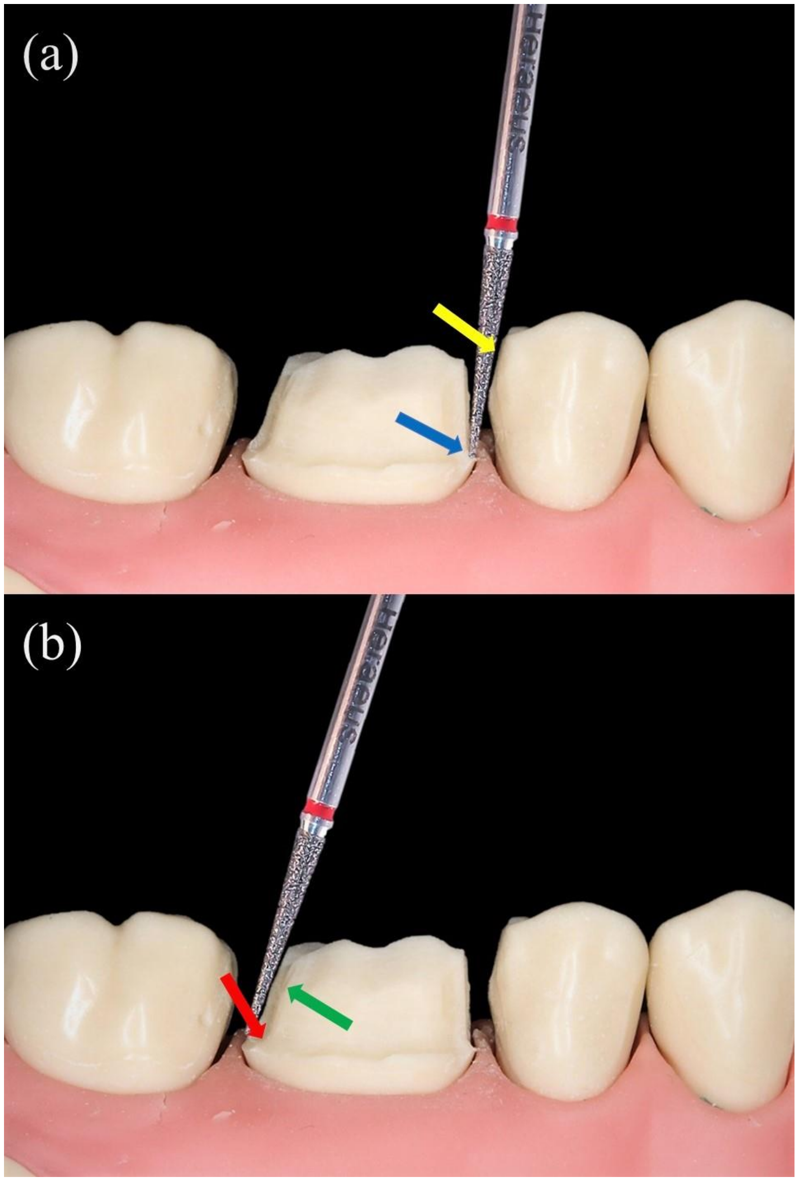

Figure 2. Clinical simulation illustrating proximal reduction using narrow needle-shaped bur. Figure (a) showed underpreparation (blue arrow), and iatrogenic damage (yellow arrow) to the adjacent teeth. Figure (b) showed overpreparation (red arrow), and overtapering (green arrow) of the prepared abutment tooth caused by tilting the bur to avoid damaging the adjacent tooth.

Figure 3. Virtual 3 D image illustrated the iatrogenic damage to the mesial surface of tooth 47 during crown preparation of tooth 46 performed by undergraduate dental student in the preclinical setting. The scan captured by Trios intraoral scanner

1.5 Protective Devices

Several preventive approaches and measures have been suggested for use during proximal tooth surface cutting with rotary instruments. Among these approaches is using a small-diameter tapering diamond instrument, as suggested by Shillingburg, Hobo, and Whitsett.[1,35] Rosenthiel and Fujimoto proposed a modified approach of initially leaving a thin lip or fin of enamel on the tooth being prepared with a fine tapering diamond bur to protect the adjacent teeth from damage.[36] This lip is then broken away and the margin trimmed in the late stage of preparation. Dykema and his coauthors suggested the use of metal bands, such as matrix bands, to isolate the adjacent teeth that are subject to possible damage.[37]

Undergraduate dental students who are novices in tooth preparation are not usually taught to use adjunctive devices to protect the adjacent teeth during tooth preparation. Nonetheless, some students may tend to place a conventional dental wedge interdentally and/or use Universal matrix bands on the adjacent teeth to protect them during proximal preparation.[8] However, this matrix is very thin and easily deformed if pressure is applied while placing it. The matrix may also be perforated easily once the bur touches it. Dental students are routinely taught to use an interdental wedge to secure various types of matrix bands against the tooth while restoring class II tooth cavities with filling materials. Students are also routinely taught that a dental wedge can create a modest, temporary interdental separation between teeth if desired to improve operator access to the proximal surface or to improve the proximal contact possible with a subsequent direct restoration. The dental wedge has a triangular cross-section with a narrow edge on the stem. Therefore, the wedge is most appropriate for insertion at the base of adjacent teeth in the gingival embrasure area where undesirable movement of filling material is most prevalent.

A new generation of dental matrixes and wedges has been introduced into the dental market as novel protective aids for use during proximal tooth preparation (Figure 4). A stainless-steel matrix device (InterGuard®, Ultradent, South Jordan, UT, USA) is designed to be thin enough to accommodate most narrow proximal spaces easily. The protective matrices [FenderWedge® (Upplands Väsby, Sweden) and WedgeGuard® (Katikati, New Zealand)] are designed as a combination of a protective stainless-steel matrix and an attached plastic wedge to secure the matrix in place mainly intended for use during class II cavity preparation.[8] As with traditional dental wedges and matrix bands, these protective matrices are available in different sizes, to provide flexibility for the operator in accommodating existing contours of the gingival embrasure and depending on the desired separation and stability needed during the interproximal preparation.

Manufacturers of these products suggest that these matrices have a higher protective efficiency of adjacent teeth during tooth preparation than possible with conventional methods. However, the new matrices still lack solid scientific evidence on their efficacy and effectiveness to protect adjacent teeth during preparation. An initial study has demonstrated the efficacy of the protective matrices on class II cavity preparation,[8] but to the best of my knowledge, no study has investigated the protective effect of these devices during crown preparation.

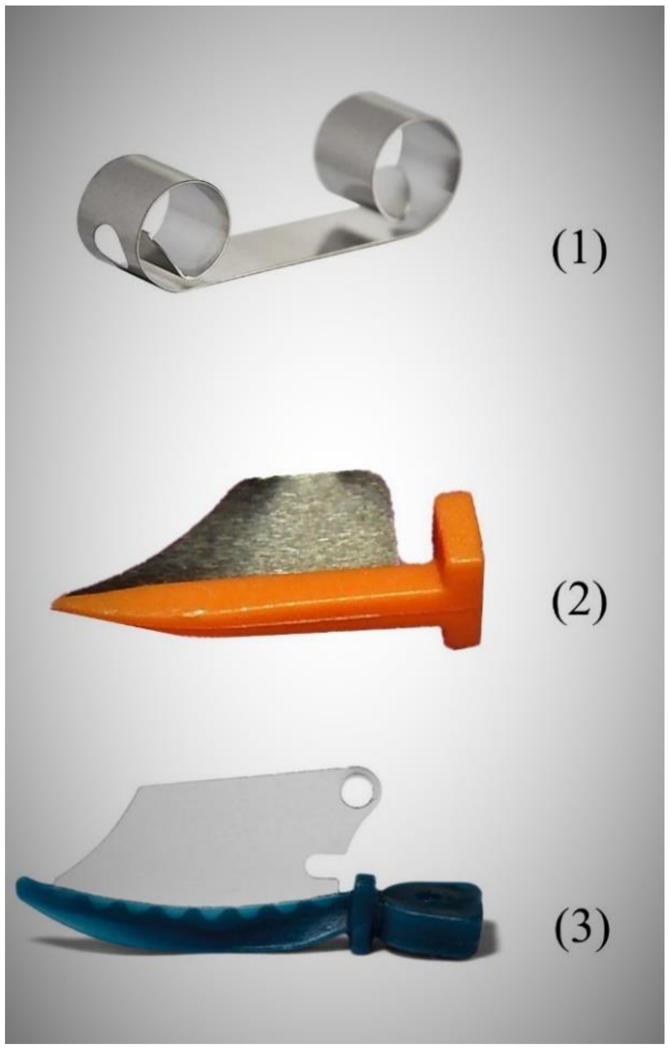

Figure 4. Available novel protective aids with different designs for proximal tooth preparation. (1) InterGuard, (2) FenderWedge, and (3) WedgeGuard

1.6 Assessment in Fixed Prosthodontics Simulation

Assessment is an integral part of dental education. Preclinical assessment in the fixed prosthodontic learning environment is a process by which a student's performance and quality of tooth preparation outcomes are evaluated. This assessment is used to determine whether the student has gained the appropriate skills that will allow him/her to safely proceed to the next stage of their clinical training with supervised patient care.

An ideal assessment tool would have the following characteristics: validity, reliability, accountability, comprehensiveness, viability, relevance and timeliness.[38] In this context, validity refers to the ability of the assessment to accurately measure the criteria of the tooth preparation. The process of validation involves accumulating evidence to provide a sound scientific foundation for proposed score measurements.[38] Reliability refers to evidence of the consistency (or reproducibility) of results over time when repeated measurements are made. If an assessment tool is reliable, then the same results should occur over multiple tests, regardless of who administers them and when.[39]

To promote more reliable and accurate assessment by the preclinical and clinical instructor, the Commission on Dental Accreditation mandates the incorporation of assessment forms and instructor calibration for dental schools in North America.[40]

1.6.1 Subjective Assessment of Iatrogenic Damage

Tooth preparation assessment by the clinical instructor in preclinical and clinical environments is a critical component of the student's dental education in fixed prosthodontics. In preclinical practice, it is crucial that students receive consistent feedback on and assessment of their preparations from the instructor in the cognitive stage of learning. Such assessments will help students to understand effective application of the principles of tooth preparation, and to continually improve their performance in producing geometrically acceptable preparations prior to clinical practice at the associative stage in their dental education.

In 1982, Mackenzie and his colleagues[41] reported multiple areas that may reduce the accuracy of subjective assessments conducted by preclinical instructors. These areas include unspecified or inconsistent observation methods, memorizing the instructional materials, lack of training, incomplete coverage of dimensions, undersized aids to judgment, incomplete or ambiguous operational definitions, unsystematic inspections, discrepancies in visual acuity, the instructors' degrees of leniency, differences in mental processing, and differences in specialty, background, and ability.

In 1993, Feil and Gatti suggested implementation of instructor calibration and well defined grading criteria to overcome disagreements between instructors and inconsistent assessments, including rater calibration, grading scales, training, and subjective influences.[22] The main purpose of calibration is to achieve standardization among instructors. In other words, calibration is implemented to achieve consistent application of protocols and assessments, so the student experience is as consistent as possible. Instructors' differing feedback or assessments on the same student's performance may confuse the student and damage the student's trust in the learning process. Calibration of the instructors establishes an effective, consistent, and accurate assessment of students' performance and so offers the possibility of creating a constructive and positive student learning environment to enhance student achievement.

When instructor standardization is accomplished, both inter-rater and intra-rater reliability scores should be high. Inter-rater reliability is the degree of agreement among different instructors, which helps determine if a certain test is appropriate for measuring a specific skill. If various instructors do not agree, either the scale is defective, or the instructors need to be recalibrated. However, regardless of these signs of progress, several studies have shown that instructor inter-rater and intra-rater assessments are usually not consistent when evaluating dental student performance.[42-46] Some of the difficulties associated with instructor calibration include the number of adjunct instructors, the fact that they attended different schools at different times, the number of years of the clinical and educational experience of the instructor, the lack of time, and the growing numbers of part-time instructors.[46]

1.6.2 Digital Technologies as Objective Assessment Tools

Digital technologies including computer-aided designing and computer-aided manufacturing (CAD/CAM) technology have gradually become a popular part of dentistry over the past two decades. These technologies have recently been introduced and actively incorporated into curricula in some dental schools.[47]

In addition to providing learning experiences in a digital workflow for diagnosis and the design and manufacture of dental appliances, the main purposes for incorporating digital technologies into dental schools are to support students' motor skills learning by improved student understanding of tooth preparations in 3D space and by facilitating individual learning through objective and accurate measurements along with consistent feedback.[47] Furthermore, this technology has great potential to reduce instructor struggles with standardization and to avoid human error or bias in assessing student performance.

The initial evidence seems to indicate that using the digital approach improves objective assessment when compared with traditional instructor-based visual methods, offering better quality assessments and the potential for faster acquisition of operative skills and self-reflection[48]. However, contradictory evidence indicates students have difficulty using the technology to visualize tooth preparation errors [49] and do not necessarily improve their technical or psychomotor skills [47], which makes many schools hesitant to adopt this new technology. The reasons may include technical difficulties, limited knowledge of how to use technology, and misuse of technology by students during unsupervised practice time. In addition, this requires a large and ongoing financial investment for both the new digital technology and the human resources and time necessary to integrate the technology into the school's educational system.

Examples of technology-based CAD/CAM systems that have been investigated in preclinical education include Kavo PrepAssistant (Kavo, Biberach, Germany), PrepCheck (CEREC-Sirona, Bensheim, Germany) and E4D Compare (D4D Technologies, Richardson, TX, USA).

The Kavo PrepAssistant system, adopted in 2003, is one of the earliest types of software used for tooth preparation assessment in preclinical training.[50,51] This system allows for detailed 3D viewing of tooth preparations through photographic scanning. It has the ability to compare the image of a tooth preparation performed by a student with the image of an ideal preparation performed by an instructor. The PrepAssistant software can also quantify geometric variations between the two preparations at given geometrical points in the crown preparation. However, this system has several substantial drawbacks, including a demand to isolate the individual plastic tooth in the scanner without the adjacent teeth. It can also give inconsistent readings, especially when using plastic teeth from other brand manufacturers.[51]

PrepCheck is one of the systems that is currently available on the market.[47,52] This system allows for detailed 3D viewing of tooth preparations through stitching of individual image acquisition based on intraoral scans, and is reliable, which makes this system available in both preclinical and clinical applications. This CAD/CAM educational tool was developed by Sirona Dental Systems (Long Island City, NY, USA), and it can create a 3D printed model of the student's crown preparation from a typodont model. In the preclinical setting, the student's crown preparation can be compared with either an unprepared typodont tooth or a master preparation performed by the instructor.[47] These virtual model images can be rotated and viewed from any angle, and tools in the software can be used to measure and evaluate the tooth preparation. Although some studies reported an advantage to the objective assessment of the PrepCheck system,[52-54] others have doubted the benefit of using this system and suggest further studies to investigate the possible educational outcome.[47,55,56]

E4D Compare software is another CAD/CAM educational tool that uses a similar principle to the PrepCheck system of evaluating the digital model of a student's crown preparation by superimposing it over a digital model of an ideal crown preparation performed by the instructor.[48,57,58]

A recent educational study published by Gratton and his coauthors compared E4D Compare and PrepCheck and showed there is no difference in student performance outcomes and perception when these systems are used as additional tools of instruction along with the traditional instructor feedback.[56] However, the instructors pointed out that the E4D Compare system has an advantage over PrepCheck, due to its "data density view," allowing the student to confirm the quality of the scanned project and take additional scans of the project if the scan was insufficient. In addition, student's prep can be compared to either an unprepared typodont tooth or a master preparation performed by the instructor.

All of these systems can calculate total tooth reduction and convergence and display the taper and depth of axial reduction at or above the margin and the location and depth of undercuts, the latter being axial contours along the selected path of insertion of the preparation that have a narrower diameter than the contours further occlusal. However, there does not appear to be a software system that has been used to investigate and evaluate the iatrogenic damage to adjacent teeth during crown preparation.

Since the late 2000s, there has been a rapid increase in the number of commercial intraoral scanners (IOS). However, these IOS scanners use different acquisition techniques and software algorithms, which influence each scanner's accuracy and precision.[59-62] Furthermore, these differences may influence the possibility of identifying and capturing the fine details of a tooth preparation like the margin (or finish line).[59] Researchers have adopted common definitions of accuracy and precision. Accuracy is defined as the ability of a measurement to match the actual value, and precision is defined as the ability of a measurement to be consistently reproduced.[60] Current data suggests that intraoral scans are highly accurate when scanning single or partial fixed prosthesis preparations, but less accurate when scanning complete arches.[60-62] It has also been reported that the IOS more reliably and accurately records abutment tooth preparations, independent of their geometry, in comparison to less accuracy with the digitized data of conventional elastomeric impressions produced by an extraoral digital scanner.[61]

A recent study investigated the level of finish line accuracy among seven IOSs. The study showed that the TRIOS and CS3600 scanners had the highest finish line accuracy.[59] Another study showed the superiority of the TRIOS scanner when the accuracy and precision of four intraoral scanners were compared in scanning oral implants.[63]

1.6.3 Iatrogenic Damage Assessment

Several tools have been proposed to assess the iatrogenic damage of adjacent teeth during restorative procedures. Among these tools are the stereomicroscope, light microscope, scanning electron microscope (SEM), modified digital micrometer caliper, 3D visible light profilometer, and 3D visible laser profilometer. However, to date, no single method is considered the gold standard for objective assessment of iatrogenic damage of adjacent teeth during crown preparation.

In 1992, Qvist and his coauthors [12] were among the earliest investigators to use stereomicroscopy to examine iatrogenic damage of the models reproduced from alginate impressions. However, the use of alginate does question the accuracy of capturing defects on the tooth surface being a frequency of only 69% of damage reported compared to 89% of damage reported in another study by Lussi and Gygax (1998), using the same technique (stereomicroscope) on dental models reproduced with elastomeric impression materials.[28]

In 2000, Meideros and Seddon used light-body polyvinylsiloxane impressions to capture the surfaces of the teeth adjacent to class II restorations. The frequency of iatrogenic damage was found to be 60%. These impressions were examined by light microscope and SEM for iatrogenic damage.[11] Furthermore, in the study by Abdulwahhab and his coauthors (2014) dental stone casts were reproduced from silicon impressions to measure the depth of the damaged teeth using modified digital micrometer caliper.[7] As noted they reported that the frequency of surface damage was found to be as high as 98.2%.

Recently, Milic and his coauthors were among the earliest to investigate iatrogenic damage using a 3D visible light profilometer and a 3D visible laser profilometer of the same accuracy to measure the depth of the damage to typodont teeth adjacent to class II cavity preparations.[8] This tool has been used primarily in dental studies evaluating and measuring implant surface roughness.[64]

Overall, even though substantial work has been done to measure the damage of adjacent teeth using the previous tools, there has been a lack of study measuring iatrogenic damage to surfaces of adjacent teeth compared with the native surfaces prior to crown preparation.

Chapter 2: Aims, Objectives and Hypotheses

The primary aim of this project was to determine the students' performance during crown preparation implementing the use of a protective matrix for reducing the iatrogenic damage to adjacent teeth during the proximal wall preparation in a preclinical setting. The secondary aim was to begin to explore the characteristics of evaluations of iatrogenic damage to adjacent teeth during proximal wall preparation, using digital technology.

2.1 Objectives and associated Null Hypotheses

Objective 1: To determine if a novel protective matrix used by dental students for the performance of proximal reduction during crown preparation can reduce iatrogenic damage to adjacent teeth.

This objective is related to the primary study aim and to the following primary null hypothesis H01.

> **H01:** A novel protective matrix does not improve dental student performance of proximal reduction during crown preparation in relation to iatrogenic damage to adjacent teeth.

Objective 2: To begin to explore the accuracy and consistency of evaluations of iatrogenic damage to adjacent teeth during proximal wall preparation, using digital technology.

This objective is related to the secondary study aim, leading to the following secondary null hypothesis H02.

> **H02:** The objective assessment of iatrogenic damage to adjacent teeth with digital technology has similar accuracy to traditional subjective faculty-member assessment.

Chapter 3: Materials and Methods

3.1 Study Design

A total of 60 undergraduate dental students in the second-year of their Doctor of Dental Medicine (DMD) program at the University of British Columbia (UBC) Faculty of Dentistry volunteered and signed a consent (Appendix A) to participate in this preclinical, quasi-randomized, crossover educational study during their fixed prosthodontics simulation course in the 2017/2018 academic year. Ethical approval (Appendix B) for the study was granted by the UBC Behavioural Research Ethics Board, Vancouver, BC, Canada (reference number: H17-02108).

The DMD second-year course is the usual setting for novice participative learning related to crown preparation and, as part of this, the dental students receive didactic instruction on preparing a full-metal crown and are tasked, during usual curriculum practice and also as part of this study, with preparing the mandibular right first molar (FDI tooth number 46) for a full metal crown restoration on a manikin-mounted typodont.

In keeping with the usual clinical simulation protocol, instructors closely monitored the students as they performed the crown preparation, being sure the students continued operating under the conditions of the manikin-mounted typodont. Students also wore standard personal protective clinical attire (gowns, face masks and gloves) and used their choice of highspeed air-rotor or electric micromotor hand-pieces, and burs (neodiamond ®, Egenstien-Leopoldshafen, Germany), needle diamond (#858014), reduction chamfer diamond (#878K016), and finishing chamfer diamond (#8878K016) with water spray and suction, intended to mimic a clinical setting.

Prior to the study, also as part of their usual curriculum, the students had received didactic instruction and had practice experience preparing premolar teeth for metal ceramic and all ceramic crowns, as well as instruction and demonstration on optional use of a protective steel matrix stabilized by an attached plastic interdental dental wedge (FenderWedge ®, Directa AB, Upplands, Väsby, Sweden), to help isolate posterior teeth during crown preparation. The matrix was introduced in the simulation course as optional because its effectiveness for prevention of iatrogenic damage during crown preparation had not been established. The students were also taught that the matrix is typically most stable during the initial interproximal separation for a crown preparation, but frequently needs to be removed for completion of the crown preparation as the wedge is not stable enough to remain in place through the entire axial reduction, and it would need to be removed to fully access the proximal axial surfaces for margin finishing.

The study was divided into three parts (Figure 5), completed during the academic year 2017/2018. In Part I, students were quasi-randomly assigned into two approximately equal-sized groups, based on spliting the class alphabetically using the surname; they were tasked to undertake the number 46 tooth preparation in a routine practice session according to either a traditional full metal crown preparation protocol,[65] or the same tooth preparation using a protective matrix (small orange size, FenderWedge ®) to help isolate the tooth during the crown preparation, followed by Part II as a crossover of the groups in the subsequent practice session one week later. The small size wedge was selected for use in this study as it was the most appropriate size to fit the available contours of the gingival embrasures adjacent to the number 46 typodont tooth. Assessments of the tooth preparation, at the conclusion of these practice sessions, were not counted toward formal student grades but were used in the study as described later. In Part III, one week subsequent to these initial practice sessions, again, as usual, the students undertook a timed quiz of the number

46 full metal crown preparation, the traditional subjective faculty-member assessment of which was counted toward their progress in the course; during this quiz, the use of the protective matrix was optional. Prior to each session, new typodont plastic teeth, number 46 together with adjacent teeth numbers 45 and 47, were screwed tightly into the typodont by one faculty member. For each session, two hours and 15 minutes was available to complete both the crown preparation and a composite resin (Integrity®, Dentsply Sirona Canada Ltd, Woodbridge, Ontario, Canada) provisional crown using a clear vacuform matrix, but no effort was made to differentiate the portion of time actually used to complete the crown preparation task, nor was assessment of the provisional crown considered in this study.

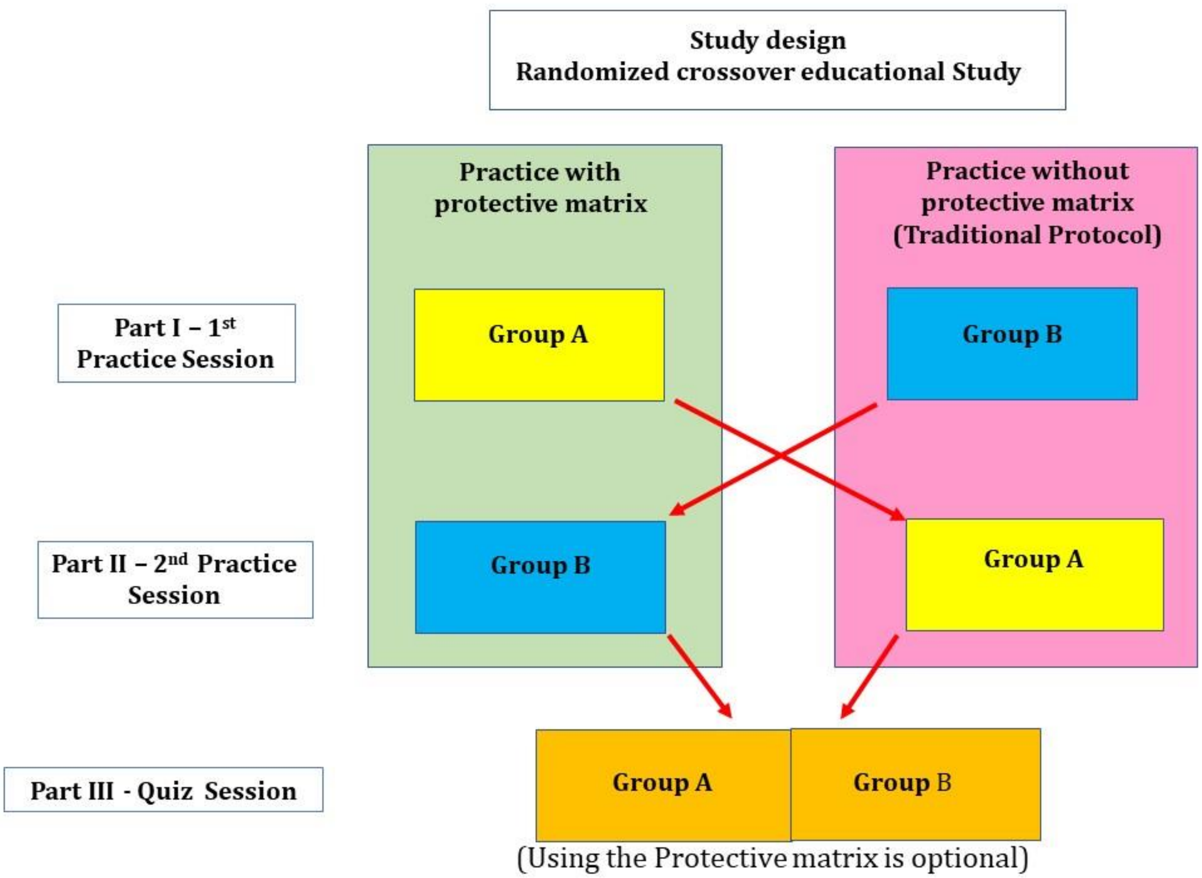

Figure 5. Flow chart of the crossover preclinical study design.

Upon completion of their tooth preparation, at the conclusion of each session, the students turned in their typodont and a preparation evaluation form (PE), separately from any used protective matrix, and a completed student satisfaction questionnaire (SQ) (Appendix C), all of which were identified only with the unique student number. The SQ recorded the student self-report on whether the protective matrix was used, and the level of student satisfaction using the protective matrix based on a visual analog scale, ranging from 0 (Very unsatisfied) to 100 (Very satisfied). The students were asked to mark an X on a 100 mm long scale, at the point they felt represented their level of satisfaction with the protective matrix. The score would be the distance, mesured in millimeters, from the left end point to the X mark.

3.2 Traditional Subjective Assessment by Faculty Members

As a usual part of the curriculum, the tooth preparation and any damage to the adjacent teeth was evaluated blindly, using only the unique student numbers rather than their names, and independently by three calibrated faculty members extraorally using 2.5x magnifying loupes (Figure 6). Calibration was done on what constitutes severe damage and how to distinguish this from minor damage. The grading of severe damage was agreed upon by the three faculty members based on visual inspection. Discrepancies in grading between faculty members were resolved by consensus at the time. This traditional subjective assessment of the crown preparation used a standard UBC Faculty of Dentistry protocol for the purposes of the present study to assess iatrogenic damage of the adjacent tooth (on the distal surface of the second premolar or/and the mesial surface of the second molar adjacent to the prepared tooth), according to established criteria within a prescribed grading scale from Satisfactory (S) for no damage, Borderline (B) for minor damage, and Unsatisfactory (U) for severe damage, where a B grade included any superficial scratch or groove damage not spread over a large area, that would clinically be able to be corrected with minor enameloplasty and remineralized with fluoride. Although some level such iatrogenic damage is nearly universal in dental practice, there are no standards for determining the clinical acceptability of minor damage. Nonetheless, the determination of minor damage in this setting was intended to respect a maximum depth of less than 120 μm.

Figure 6. Sample of typodont after removal of tooth 46 to evaluate the damage of the adjacent teeth by three calibrated faculty members extraorally using 2.5x magnifying loupes

3.3 Subjective Virtual-Assisted and Objective Digital Assessments

Surface scanning the mandibular right quadrant of each typodont, at tooth sites 45, 46 and 47, was acquired twice (before and after) for each preparation session with the 3D intraoral scanner (3Shape TRIOS®, Copenhagen, Denmark) by one faculty member using a standardized pre-preparation scan protocol to generate high-quality 3D virtual models for comparison of the superimposed surfaces of the adjacent teeth prior to and after preparation. The first scan, obtained prior to each preclinical session, was acquired immediately after placing new intact teeth 45 and 47, but without tooth 46, to capture the distal and the mesial surfaces of 45 and 47, respectively. The second scan of each typodont was obtained after each preclinical session was finished and the traditional subjective assessment was completed by faculty members. Tooth 46 was then removed from the typodont to facilitate the post-preparation scan according to the standardized pre-preparation scan protocol and identified for each typodont using the unique student number.

The scanned surfaces of adjacent teeth from each preparation were then subjectively evaluated blindly by one assessor (AB; assisted virtually by the CAD software of the Trios system, at 20x magnification) for any damage, using the same grading protocol used previously for assessment of the iatrogenic damage by calibrated faculty members extraorally. The CAD software allows an assessor to zoom the virtual 3D preparation image in/out and to rotate the image up or down and right or left, as needed, to evaluate the tooth surface from different angles. Furthermore, the CAD software allows the assessor to assess the same surfaces in real-time for any damage by comparing the pre-preparation and post-preparation scans (Figure 7). The subjective virtual-assisted assessments for Part II of the study were repeated by the same Assessor (AB) one week later to evaluate the intra-rater reliability and by another Assessor (RB) to determine the inter-rater reliability.

Subsequently, objective depth and volumetric differences between superimposed scans, representing two aspects of the damage to the adjacent teeth, were measured blindly (using the unique student numbers) and independently by one examiner, using a digital CAD system (3Shape Dental System®, Copenhagen, Denmark). Specifically, the depth of the damage on both adjacent surfaces was assessed by measuring the distance between two points in the superimposed cross-sectional images, along a line drawn perpendicular to the intact surface to the deepest point of the defect (Figure 8).

The process for objective volumetric assessment of the damage involved exporting the Standard Triangle Language (STL) scan files from the 3Shape Dental System CAD and importing them into 3D modeling software (Meshmixer v2.1; Autodesk, San Rafael, CA) to create virtual 3D models for importing into Rhino 3D software to facilitate a Boolean intersection of the models based on the surfaces of the adjacent teeth. This isolated any discrepancies in the superimposed volume elements (voxels) before and after crown preparation, representing the measure of volumetric damage to the adjacent teeth compared with the intact tooth surface before preparation (Figure 9).

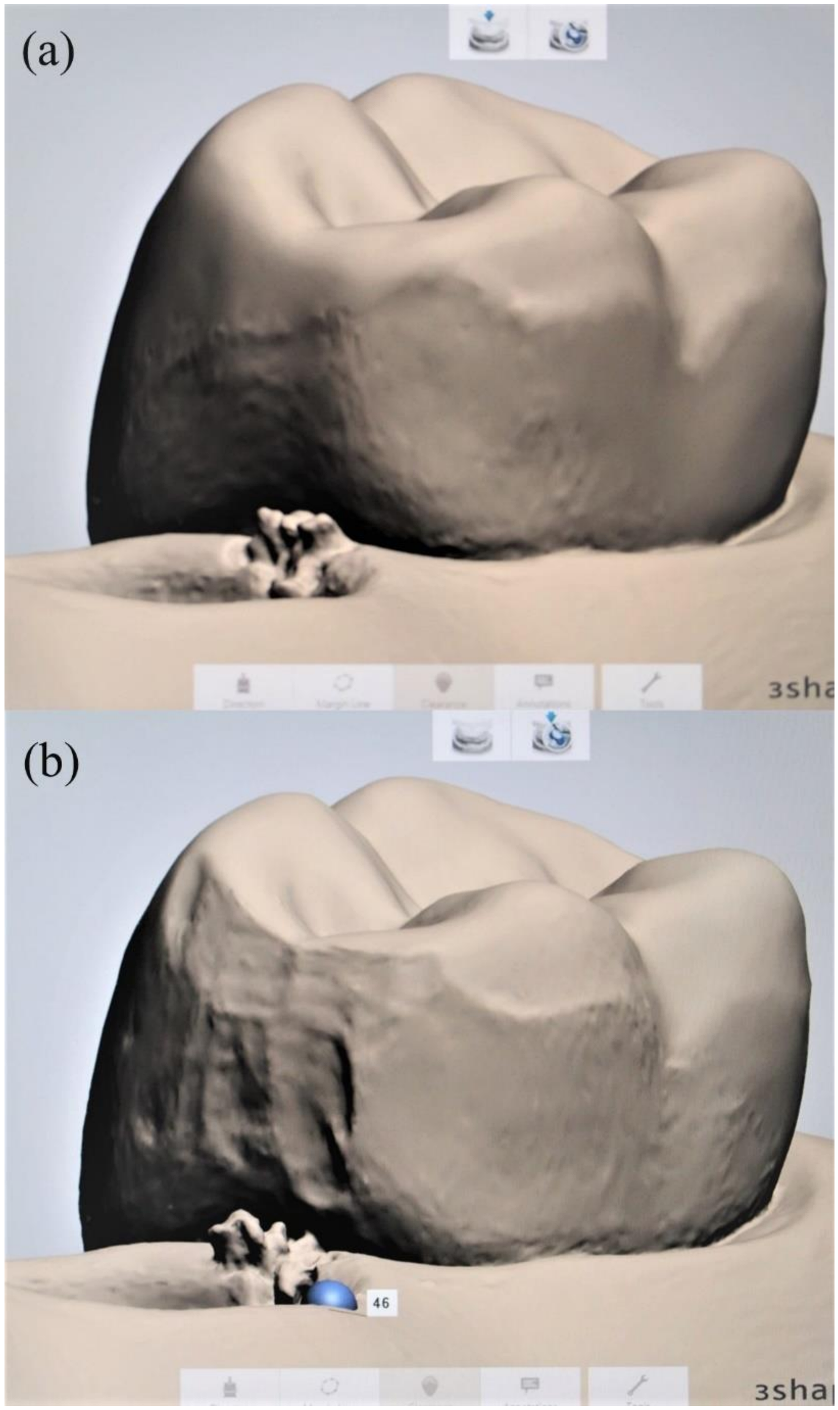

Figure 7. Virtual digital assessment of the mesial surface of tooth #47, distal to the abutment. Pre-preparation view (a) and post-preparation view (b) of the scans captured by Trios IOS.

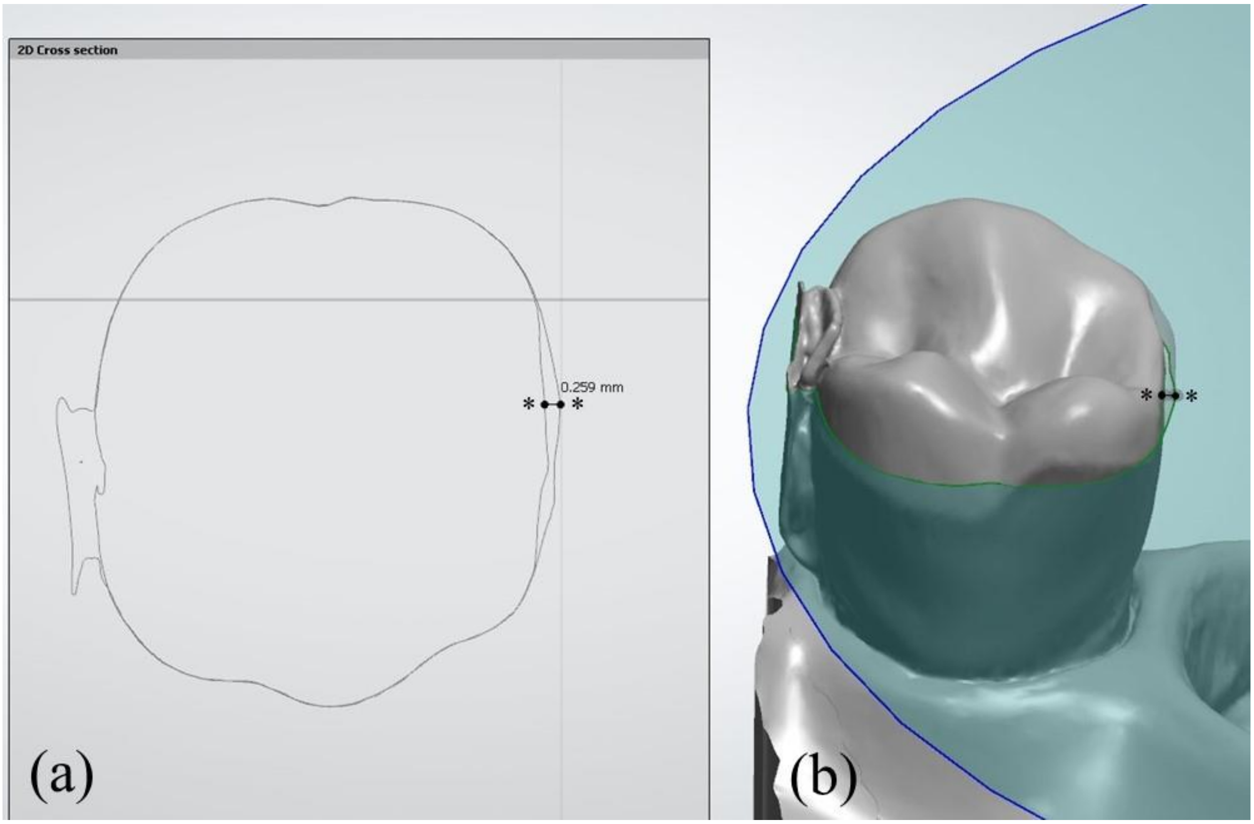

Figure 8. Sample Measurement of the damage depth using CAD dental system. A cross-section (a) and 3D images of the adjacent tooth 45 illustrate the measuring the two points of the superimposed scans from the external surface of pre-preparation to the deepest point of the defect of the damage from the post-preparation scans.

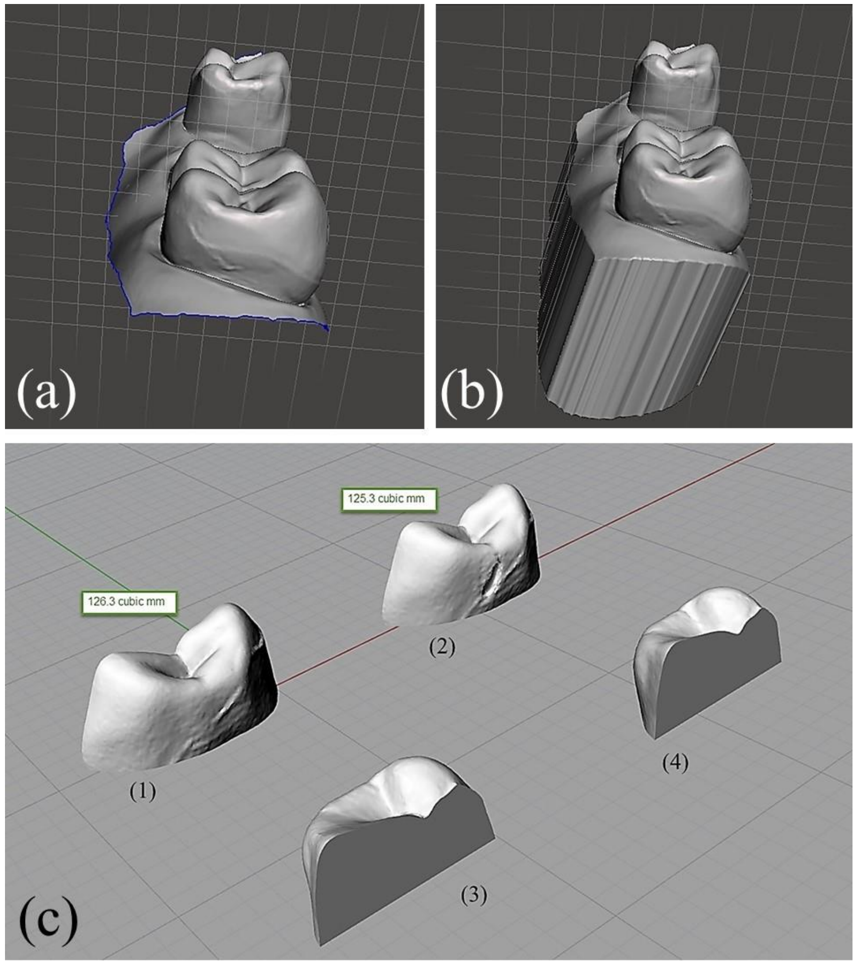

Figure 9. Sample of the Volumetric assessment process. (a) imported STL file into Meshmixer software, (b) create a solid model to perform a boolean intersection of the superimposed solid model before and after preparation, (c) illustrate the adjacent teeth surfaces of before (1, 3) and (2, 4) after preparation for mesial 47, and distal 45 respectively.

3.4 Statistical Analysis

Firstly, the comparisons of damage to the adjacent teeth between groups were analyzed with SPSS statistical analysis software as either categorical or continuous variables, depending on the measure. Specifically, data were analyzed using chi-squared tests for comparing the frequency of damage between groups as assessed both by subjective faculty-member assessments and subjective virtual-assisted assessments using the digital system (Satisfactory (S); Borderline (B); Unsatisfactory (U) grades). Independent t-tests were used to analyze the continuous data comparing depth and volumetric discrepancies. The linear regression test was used to analyse the crossover effect of students attempts during initial practice sessions and use of a protective matrix on damage as a categorical variable.

Secondly, for assessing and comparing measurement characteristics, the paired samples Wilcoxon signed-rank test was used to compare traditional subjective faculty-member assessments of adjacent tooth damage with the objective digital assessments of the depth and volumetric discrepancies. Pearson correlation analysis was also done to determine the correlation between both assessment methods. It is acknowledged that the subjective assessments of damage, although ordinal in nature, do not meet the usual assumptions needed for the analysis of continuous data. Consequently, a ranked Kendall's Tau correlation coefficient was also calculated to compare the subjective and objective assessments. For repeatability, a Cohen's kappa coefficient was used to measure intra-rater and inter-rater agreement between the examiners subjective virtual-assisted assessments. It was not possible to evaluate the agreement for repeated subjective faculty-member assessments, as these were completed as per the usual grading protocol by immediate consensus between at least two of the three calibrated instructors to arrive at a single grade. Unfortunately, it was also not possible to repeat the objective volumetric measurement process due to the cost.

Chapter 4: Results

In total 60 dental students produced 156 tooth preparations available for analysis in this study during three simulation clinic sessions. Twenty-four (13.3%) of the possible 180 preparation attempts could not be included for analysis. Six students in the first practice session and seven different students in the second practice session did not attend or did not submit their typodonts for analysis. In addition, three students were absent for the quiz session, and another student did not provide the consent form to participate in this study. A further seven preparation attempts were excluded for the quiz session either because the students did not submit the questionnaire form, making it impossible to identify which group they belonged to, or the students did not submit their typodonts prior to the session for proper placement of new plastic teeth and pre-preparation scanning.

4.1 Traditional Subjective Assessment by Faculty Members

Overall, the usual subjective faculty-member assessments found iatrogenic damage (either minimal or severe) to adjacent teeth was significantly more frequent (p=.027; Chi-Squared test) during the combined two initial practice sessions (overall 83.0% and 86.5% for the first and second sessions respectively) compared to the subsequent quiz session (overall 45.1%) (Table 1). Furthermore, there was no difference (p= .76; Chi-Squared test) in the overall frequency of damage comparing the two practice sessions.

In general for the subjective faculty-member assessments, comparing the outcomes with and without the protective matrix in the three sessions, there was a consistent tendency for less frequent damage to the adjacent teeth when students used the protective matrix as compared to when students did not use it (Table 1). However, this tendency was only statistically significant during the second practice session (Table 1), when considering the three parts of the study individually. To further test the time-effect of the cross-over group assignment on the frequency of damage during practice sessions, a linear regression model of the incidence of damage revealed that the effect of both the cross-over group assignment and the use of a protective matrix during the crossover, and the interaction between these two factors, were all non-significant (p=0.064) associated with the protective matrix group.

Evidence of this lack of time-effect of the cross-over group assignment on the damage outcomes suggests also the importance and statistical viability of assessing the combined outcome of the two practice sessions. Comparing the results for the protective matrix and no-protective matrix groups during the combined two initial practice sessions, there was significantly less frequent (p=.027; Chi-squared test) damage to the adjacent teeth when the protective matrix was used (76.9%) compared to when it was not used (92.5%). Correspondingly, the combined first and second practice session data showed a significantly (p=.027; Chi-Squared test) higher frequency of students with no damage to the adjacent teeth when the protective matrix was used (23.1%) as compared to when the matrix was not used (7.5%). Likewise, the combined two initial practice sessions demonstrated a significantly (p=.034; Chi-Squared test) lower frequency of severe damage to the adjacent teeth when the protective matrix was used (25.0%) compared to when the matrix was not used (43.4%). As noted, the quiz session also yielded this tendency, although not statistically significant (p=.08; Chi-squared test), of less frequent damage to the adjacent teeth when the protective matrix was used (54.8%) compared to when it was not used (30%).

Table 1. Percentage of teeth damaged during preparation with and without the use of protective matrix, by type of damage using traditional subjective faculty-member assessments.

MEASUREMENTS	**No FW group**	**FW group**
	N of total (%)	N of total (%)
No Damage		
1st session	3/27 (11.1)	6/26 (23.1)
2nd session	1/26 (3.8)	6/26 (23.1)*
Combined 1st & 2nd sessions	4/53 (7.5)	12/52 (23.1)*
3rd session (Quiz)	14/31 (45.2)	14/20 (70.0)
Minimal Damage		
1st session	11/27 (40.7)	12/26 (46.2)
2nd session	15/26 (57.7)	15/26 (57.7)
Combined 1st & 2nd sessions	26/53 (49.1)	27/52 (51.9)
3rd session (Quiz)	12/31 (38.7)	4/20 (20.0)
Severe Damage		
1st attempt	13/27 (48.1)	8/26 (30.8)
2nd attempt	10/26 (38.5)	5/26 (19.2)*
Combined 1st & 2nd attempts	23/53 (43.4)	13/52 (25.0)*
3rd session (Quiz)	5/31 (16.1)	2/20 (10.0)
Any Damage (minimal + severe)		
1st attempt	24/27 (88.9)	20/26 (76.9)
2nd attempt	25/26 (96.2)	20/26 (76.9)*
Combined 1st & 2nd sessions	49/53 (92.5)	40/52 (76.9)*
3rd session (Quiz)	17/31 (54.8)	6/20 (30.0)

* $P<0.05$, Chi Square test

4.2 Subjective Virtual Assessment using the Digital System

Subjective virtual-assisted evaluation of the 3D images of the adjacent teeth showed a variation in the type of iatrogenic damage in the form of broad shallow abrasion, longitudinal grooves, horizontal grooves, multiple grooves, and extensive abrasion, as well as a mixed type of damage (Figure 10).

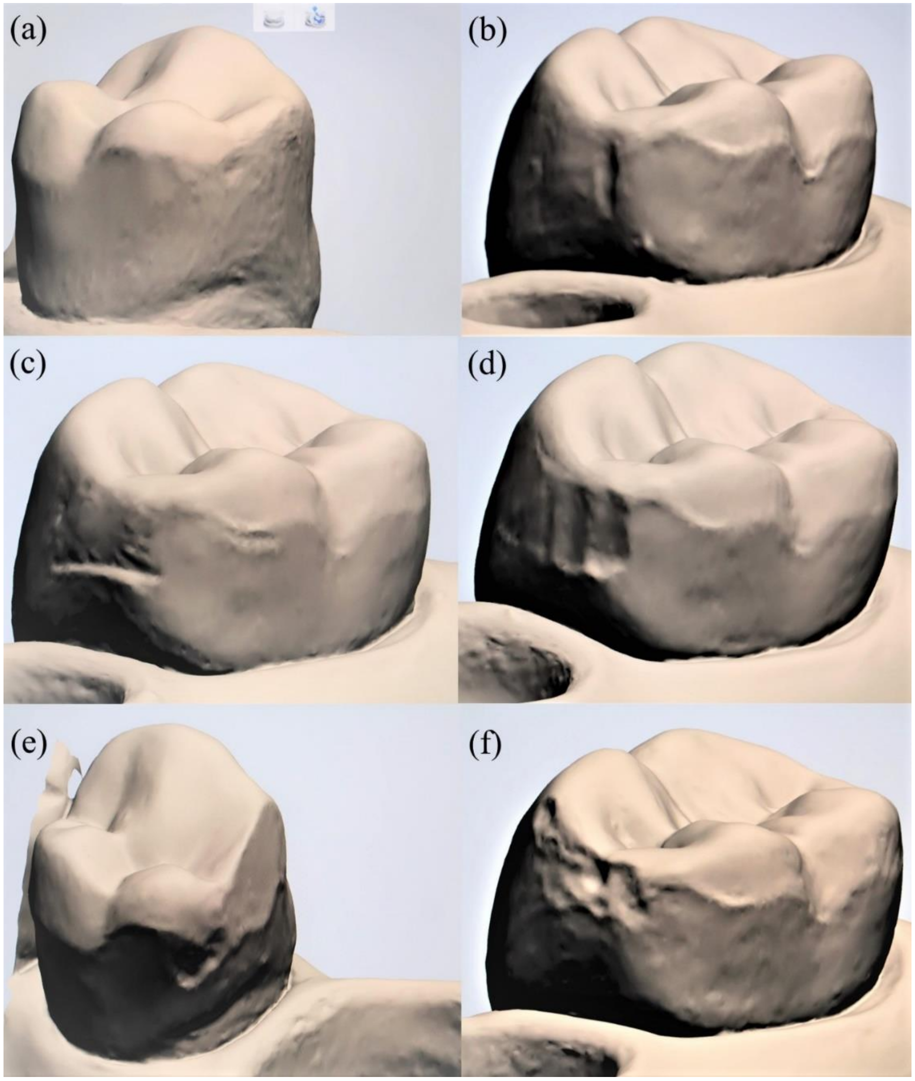

Figure 10. Subjective virtual assessment using the digital system showing different types of iatrogenic damage in the form of broad shallow abrasion (a), longitudinal groove (b), horizontal groove (c), multiple grooves (d), extensive abrasion (e), mixed type damage (f).

The subjective virtual-assisted digital assessments of iatrogenic damage to adjacent teeth showed a similar pattern of damage compared to the subjective faculty-member assessments, but with a slightly higher frequency of damage detected (Table 2). Comparing the results for the protective matrix and no-protective matrix groups, the combined two initial practice sessions again showed a significantly (p=.009; Chi-squared test) lower frequency of damage to the adjacent teeth when the protective matrix was used (82.4%) compared to when it was not used (98%). Correspondingly, the virtual-assisted digital assessment data for the combined first and second practice sessions showed a significantly (p=.009; Chi Square test) higher frequency of students with no damage to the adjacent teeth when the protective matrix was used (17.6%) as compared to when the matrix was not used (2%). Again, as with the subjective faculty-member assessments, the combined two initial practice sessions also demonstrated significantly (p=.017; Chi Square test) less frequent severe damage of the adjacent teeth when the protective matrix was used (35.3%) compared to when the matrix was not used (59.2%).

The subjective virtual assessments also showed a similar tendency of less frequent damage during the subsequent quiz session when students were practicing with (55%) compared to without (77.8%) the protective matrix, but the difference was not statistically significant (p=0.149; Chi Square test).

Table 2. Percentage of teeth damaged during preparation with and without the use of protective matrix by type of damage. Virtual digital assessment using Dental System at 20 x magnification.

MEASUREMENTS	No FW group	FW group
	N of total (%)	N of total (%)
No Damage		
1st session	1/27 (3.7)	5/26 (19.2)
2nd session	0/22 (0)	4/25 (16)*
Combined 1st & 2nd sessions	1/49 (2)	9/51 (17.6)*
3rd session (Quiz)	6/27 (22.2)	8/19 (42.1)
Minimal Damage		
1st session	11/27 (40.7)	11/26 (42.3)
2nd session	8/22 (36.4)	13/25 (52)
Combined 1st & 2nd sessions	19/49 (38.3)	24/51 (47.1)
3rd session (Quiz)	17/27 (63)	10/19 (52.6)
Severe Damage		
1st attempt	15/27 (55.6)	10/26 (38.5)
2nd attempt	14/22 (63.6)	8/25 (32)*
Combined 1st & 2nd attempts	29/49 (59.2)	18/51 (35.3)*
3rd session (Quiz)	4/27 (14.8)	1/19 (5.3)
Any Damage (minimal + severe)		
1st attempt	26/27 (96.3)	21/26 (80.8)
2nd attempt	22/22 (100)	21/26 (84)*
Combined 1st & 2nd sessions	48/49 (98)	42/51 (82.4)*
3rd session (Quiz)	21/31 (77.8)	11/20 (55)

* $P<0.05$, Chi Square test

4.3 Objective Digital Assessment

Although no standards exist for determining the clinical acceptability of objectively measured iatrogenic damage to the proximal surfaces of teeth, the objective digital assessment of adjacent tooth damage showed a high overall frequency of damage deeper than 0.12 mm (Table 3), and, again, this was substantially more frequent than the presence of any damage found with the subjective faculty-member assessments. During the two combined initial practice sessions the mean depth scores were (0.281 ± 0.14) mm without a protective matrix and (0.216 ± 0.13) mm with a protective matrix (Figure 11), which was significantly deeper iatrogenic depth damage ($p = .041$; independent t-test) without the protective matrix. However, during the quiz session, there was no significant difference between the two groups ($p = .209$; independent t-test), although there was still the same tendency for a slightly deeper mean depth score of (0.168 ± 0.13) mm without the protective matrix compared to (0.117 ± 0.09) mm with a protective matrix (Figure 12).

In contrast, the objective volumetric results did not confirm either a consistent tendency or a significant difference between the two groups regarding iatrogenic damage during the practice and quiz sessions (Figures 13 and 14). During the practice sessions the combined mean volumetric damage scores were nearly identical at (2.72 ± 2.1) mm^3 without the protective matrix, and (2.81 ± 2.9) mm^3 with the protective matrix ($p = .87$; independent t-test). In comparison, the volumetric damage scores for the quiz session were (2.18 ± 1.9) mm^3 without the protective matrix, and (1.39 ± 1.1) mm^3 with the protective matrix ($p = .475$; independent t-test).

As noted, there are no standards for determining the clinical acceptability of objectively measured iatrogenic damage to the proximal surfaces of teeth. Nonetheless, to further explore the effect of the protective matrix on the severity of the damage depth, a cut off was made to dichotomize the depth data as $\leq$0.12 mm and >0.12 mm, based on the purported increased susceptibility to caries if iatrogenic damage is deeper than 120 µm on the proximal surfaces of posterior teeth.[13] On this basis, comparing the results for the protective matrix and no-protective matrix groups during the combined two initial practice sessions did then demonstrate a significantly (p=.035; Chi-squared test) lower frequency of damage to adjacent teeth >0.12 mm deep when the protective matrix was used (72.7%) compared to when it was not used (90.9%) (Table 3). Correspondingly, the combined first and second practice session data showed significantly (p=.035; Chi-squared test) higher frequency of students with no or minimal damage (<0.12 mm) to the adjacent teeth when the protective matrix was used (27.3 %) as compared to when the matrix was not used (9.1 %). Furthermore, the maximum damage to the adjacent teeth during the two initial practice sessions was as deep as 0.62 mm with the group practicing without the protective matrix, whereas the deepest damage for group using the protective matrix was 0.51 mm. As well, in the combined practice sessions, students not using the protective matrix always produced some damage, whereas no damage was found about 3.8% of the time when the protective matrix was used.

Likewise, the frequency of a damage depth >0.12 mm during the quiz also showed a similar pattern of lower frequency when students were practicing with (40%) compared to without (76.5%) the protective matrix, and again this difference was statistically significant (p=.036; Chi-squared test) (Table 3).

Table 3. Percentage of teeth damaged during preparation with and without the use of protective matrix by damage depth >0.12mm. Objective digital assessment using Dental System

MEASUREMENTS	**No FW group**	**FW group**
	N of total (%)	N of total (%)
No Damage or Minimal Damage Depth $\leq$0.12mm		
1st session	1/24 (4.2)	2/16 (12.5)
2nd session	3/20 (15)	7/17 (41.2)
Combined 1st & 2nd sessions	4/44 (9.1)	9/33 (27.3)*
3rd session (Quiz)	4/17 (23.5)	9/15 (60)*
Damage Depth >0.12mm		
1st attempt	23/24 (95.8)	14/16 (87.5)
2nd attempt	17/19 (85)	10/17 (58.8)
Combined 1st & 2nd attempts	40/44 (90.9)	24/33 (72.7)*
3rd session (Quiz)	13/17 (76.5)	6/15 (40)*

* $P<0.05$, Chi Square test

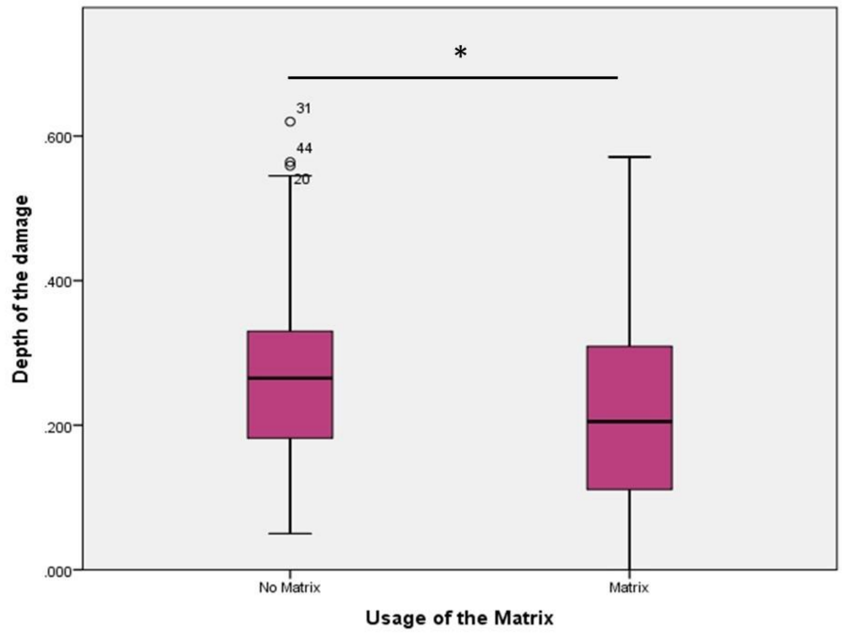

Figure 11. Assessment of impact of protective matrix on the depth of iatrogenic damage (in millimeters) of the adjacent teeth during two initial practice sessions, *significant.

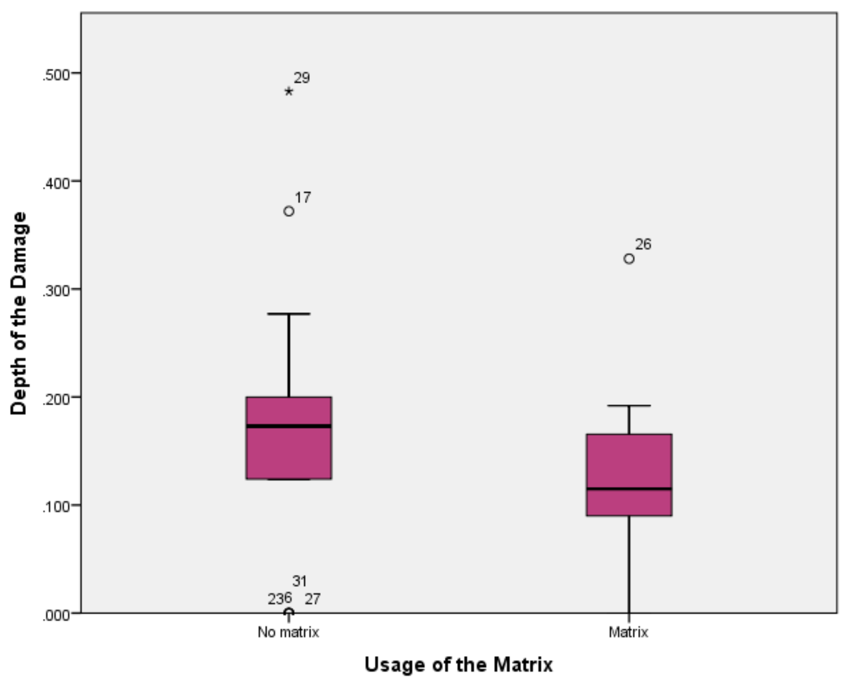

Figure 12. Assessment of impact of protective matrix on the depth of iatrogenic damage (in millimeters) of the adjacent teeth during the quiz session.

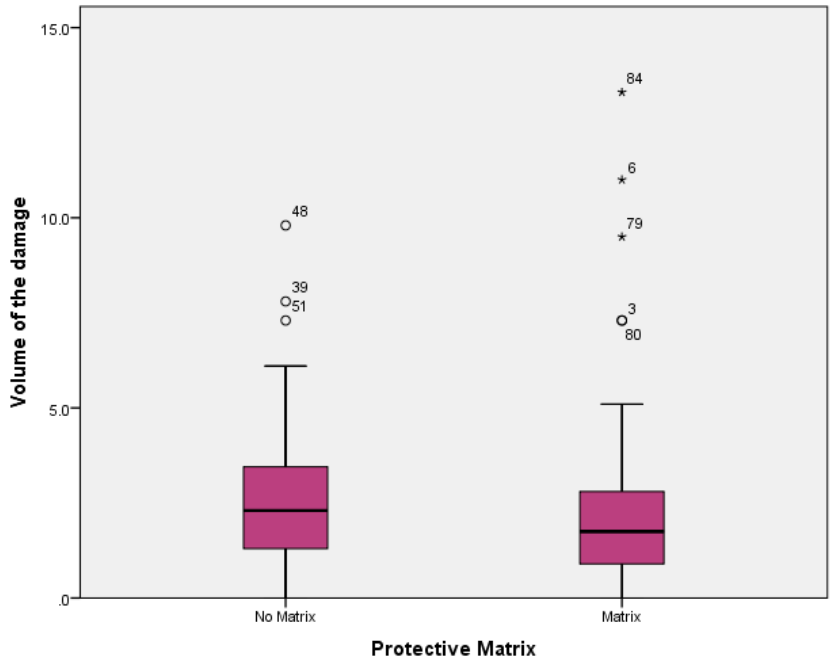

Figure 13. Assessment of impact of usage of the protective matrix on the volume of damage (in cubic millimeters) during two initial practice sessions.

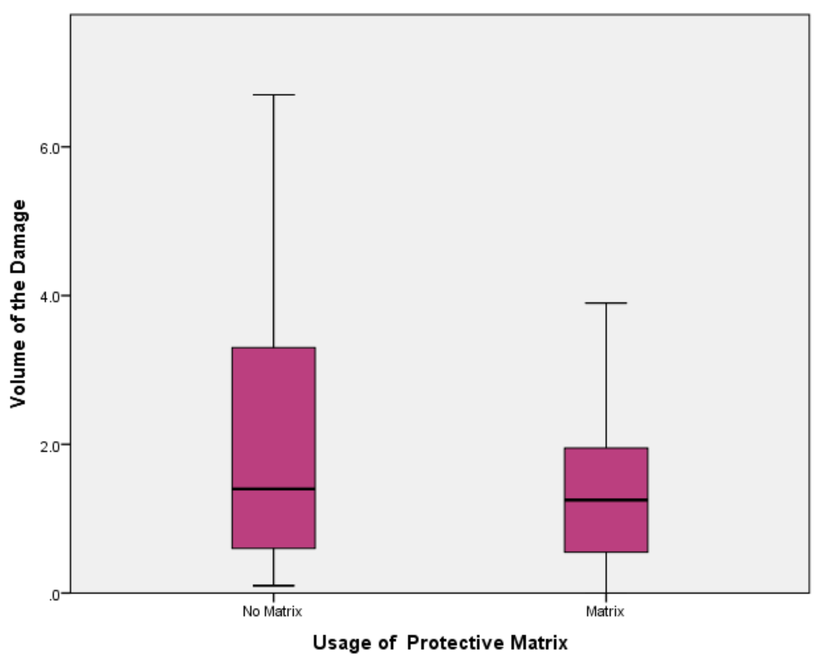

Figure 14. Assessment of impact of usage of the protective matrix on the volume of damage (in cubic millimeters) during the quiz session.

4.4 Reliability of the Subjective Virtual-Assisted Assessments and Validity Comparisons of the Different Assessment Methods.

Reliability agreement between repeated assessments using the subjective virtually-assisted assessment approach is shown in Table 4. Cohen's kappa analysis showed that the best agreement was with the intra-examiner comparison between the first (AB1) and second (AB2) assessments for one examiner, AB (K=0.58), in the upper range of moderate agreement. There was a weaker, but still moderate, inter-examiner agreement when comparing AB's two assessments with the assessments of a second examiner, RB (K=0.410 and K=0.488, for inter-examiner comparisons with AB1 and AB2 respectively).

In contrast, Cohen's kappa scores comparing damage assessments using different methods (Subjective faculty-member assessment, Subjective virtual-assisted assessment, and dichotomized Objective digital assessment) demonstrated only a fair to poor agreement between the different methods (Table 5), ranging from a high of K=0.335 and down to K=0.174.

In a further comparison of the traditional and objective methods, the paired samples Wilcoxon signed rank test showed that there was no significant difference between the traditional faculty-member assessment and the dichotomized objective assessment (p=0.782). Partly corroborating this, a Pearson's correlation analysis comparing these data revealed a significant, albeit weak, correlation (r=0.38, p=0.01) between these measures, and the Kendall's Tau correlation analysis produced the identical result.

Table 4. Intra- and Inter-rater kappa values and p-value for the subjective virtual-assisted assessments.

Reliability Comparisons	Kappa value	p-value
Assessor AB1 - Assessor AB2	0.580	<0.0001
Assessor AB1 - Assessor RB	0.410	<0.0001
Assessor AB2 - Assessor RB	0.488	<0.0001

Table 5. kappa values and p-value for the different assessment methods.

Methods Comparison	Kappa value	p-value
Subjective Assessment - Assessor AB1	0.174	0.111
Subjective Assessment - Assessor AB2	0.281	0.010
Assessor AB1 - Objective Assessment	0.245	0.032
Assessor AB2 - Objective Assessment	0.335	0.004
Subjective Assessment - Objective Assessment	0.305	0.004

Abbreviations: **Subjective Assessment** = Subjective faculty-member assessment, **Assessor AB1 and AB2** = Subjective virtual-assisted assessment (repeated twice), **Objective Assessment** = Objective digital depth assessment (dichotomized at $\leq$ or > 0.12mm)

4.5 Satisfaction Questionnaire Data

Altogether only about two-thirds of the students who reported using the protective matrix responded to the satisfaction questionnaire (SQ) on its use, amounting to 76.7%, 56.7% and 66.7%

of the matrix users during the first and second practice sessions, and the quiz session, respectively. During the practice sessions just over two-thirds of these students reported being satisfied (a VAS rating of at least 50) or very satisfied (a VAS rating of at least 75) using the protective matrix during proximal reduction, whereas nearly one-third deemed the work with the protective matrix challenging as it blocks their vision during the proximal reduction (Figure 15). In contrast, during the quiz session, a lower proportion of students were satisfied or very satisfied, and 44% were unsatisfied (a VAS rating below 50) with the protective matrix. Unfortunately it was not practical to relate the level of satisfaction with student skills performance due to the dearth of satisfaction data.

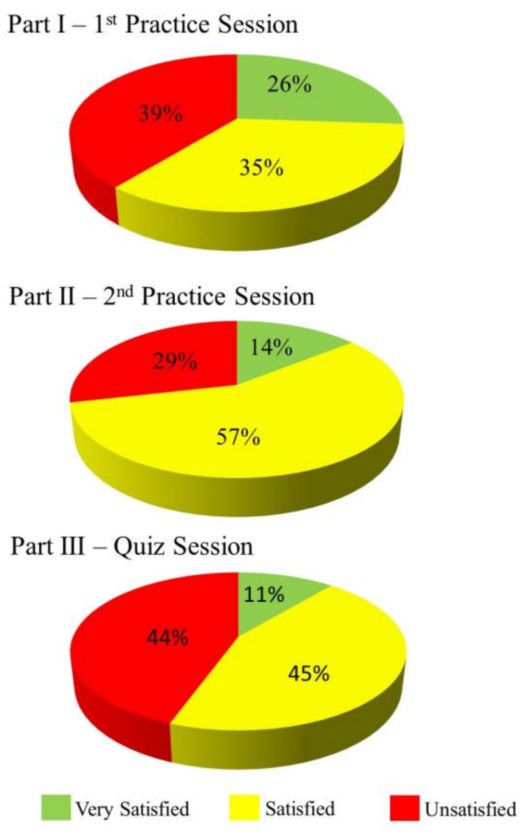

Figure 15. Percentages of student satisfaction with using the protective matrix based on a visual analog scale.

Chapter 5: Discussion

This study explores factors affecting the frequency and severity of iatrogenic damage to teeth adjacent to abutments prepared by undergraduate dental students in their early learning stages, and the potential for using digital technologies as objective tools for assessment of iatrogenic damage to adjacent teeth.

There are variations in tooth preparation for the full crown that depend on the restorative material chosen in accordance with the specific needs of the case identified by the clinician.[65] The preparation of the mandibular right molar by undergraduate dental students for full metal crown restoration was chosen to test our hypotheses in this study because this conservative preparation is a challenging task for early learners, especially the proximal reduction and the need to avoid damaging the adjacent teeth.

The results of this educational study readily confirm that iatrogenic damage to teeth adjacent to abutments prepared by undergraduate dental students is far from negligible during early learning stages, as damage was caused by nearly 9 in 10 students during the initial practice sessions. However, less than half of the dental students caused damage during the subsequent quiz session, which was expected, as their skills at this stage had gradually improved due to continual practice and their fine motor skills had become better and more consistent.

My results reject the primary null hypothesis, as the use of a protective matrix significantly reduced the frequency of iatrogenic damage to adjacent teeth during preclinical crown preparation. The faculty-member assessments found that when using a protective matrix, students caused a much lower frequency of severe damage to adjacent teeth, and less frequent damage overall (severe and minimal) than those students practicing without the protective matrix during the early learning stage. However, there was no significant difference between the protective matrix and no protective matrix groups in terms of decreasing the frequency of minimal damage, suggesting that the most important effect of the matrix was in reducing what faculty members assessed as severe damage. The results also indicate a non-significant tendency for less frequent damage to adjacent teeth during the quiz session as compared to the previous practice sessions. The possible explanations for this are a combination of gradually improving preparation skills, and that the students take the quiz more seriously than the practice sessions, the students' performance improved over time, and the sample size being smaller for the quiz due to optional use of the protective matrix and less consistent participation.

The high frequency of iatrogenic damage to teeth adjacent to abutments prepared during the initial practice sessions without use of the protective matrix concurred with the findings of previous retrospective studies on iatrogenic damage during full crown preparations.[7,9]

Abdulwahhab and his colleagues [7] also reported that nearly all undergraduate dental students damaged the teeth adjacent to crowns prepared conventionally in their study. However, the frequency of damage was lower, although still too high, in the study of Moopnar and Faulkner, at just 73.8% overall. The diverse range of experience of their study group could explain this result, as the preparations were performed by experienced dentists and graduate and undergraduate students.[9] Our results also agree with those of the only published preclinical simulation study, reported by Milic and his colleagues on class II cavity preparations by undergraduate students, which found a frequency of more than 94% iatrogenic damage to the adjacent teeth.[8]

Although, Moopnar and Faulkner [9] were, in 1991, early investigators who emphasized the need for a preventive approach to minimize the potential for accidental damage of adjacent teeth during crown preparation, significant gaps in the literature remain about effective preventive approaches, and the influence of such approaches on overall performance during crown preparation.

I also hypothesized that there would be agreement between the subjective and objective assessments of the iatrogenic damage to the adjacent teeth, such that the digital tools would have similar ability to that of the traditional calibrated faculty members in detecting iatrogenic damage. On evaluating the relationships between the assessment methods, I found that the faculty members seemed to be lacking the degree of depth perception for damage available when using the digital system. Indeed my analysis demonstrated only a relatively weak correlation between the objective digital and traditional faculty-member assessments.

My results further demonstrate that a virtual digital assessment using images of teeth scanned with an IOS enhances the visualization and detection of iatrogenic damage. Still it is important to acknowledge that although the frequency of damage is somewhat higher with the subjective virtual-assessment than with the traditional subjective faculty-member assessments, regardless of which assessment method was used there was a similar pattern of significantly less frequent damage associated with the use of a protective matrix during the two initial practice sessions.

The results also demonstrate moderate intra-rater reliability using the subjective virtual-assessment for assessment of iatrogenic damage. However, even with this enhanced technology, neither examiner AB nor RB achieved an optimal intra-rater agreement of 0.8. However, they were very close, and their scores were similar to those of graders in other studies that report only fair to moderate agreement when grading preclinical tooth preparations and dental morphology exercises.[42,66]

In comparison, agreement between the subjective virtual-assisted assessment and the subjective faculty-member assessment was only very modest. The explanation for this is probably that the subjective virtual-assisted assessment has an advantage in the evaluation and detection of damage due to higher magnification, at 20 x magnification over the traditional faculty-member assessment using 2.5x magnifying loupes. In addition, the CAD software has a unique feature that allows the assessor to view the same surfaces of the adjacent teeth in real-time for any damage by comparing the pre-preparation and preparation scans, which makes detection of the damage easier. However, this feature can only practically be of help for assessment of proximal damage with a typodont since the tooth to be prepared has to be removed temporarily for scanning prior to its preparation.

Perhaps even more consequential, the results of the objective digital assessment demonstrate a frequency of what can be considered to be severe damage, deeper than 120 µm, that is higher than the frequency of severe damage detected with either of the other two methods, but likely to be most accurate, based on the theoretical precision of the method. At any rate this finding provides even more conclusive evidence that using the protective matrix may well decrease the caries risk by decreasing the damage depth, as Kuhar and coauthors demonstrated with their work on the increasing permeability of enamel by acidic molecules in cases of damage deeper than 120 µm.[13]

With some additional exploration of the evidence on this, I also note here that the traditional subjective assessments were not able to identify a moderate amount of the minimal damage that the objective digital assessments were able to find. Specifically, during the practice sessions the traditional subjective assessments evidently failed to detect minimal damage created by about 1 to 2 out of every 10 students, who were evaluated subjectively as having no damage, since a detailed look at the objective data showed that only 3.8% of the same students completely avoided detectable damage to the adjacent teeth when using the protective matrix, while no students completely avoided damage without the protective matrix. As further evidence that the faculty members were lacking some depth perception in detecting damage with the traditional approach, the subjective data also found that about half of the students created what was considered to be minimal damage whether or not they used the protective matrix during the practice sessions, compared to the objective data, which showed minimal damage ($\leq$ 120 μm) by less than 1 in 10 of the students not using the matrix and less that one quarter of the students using the matrix. In other words, a substantial amount of the damage that the faculty members thought to be minimal could actually be considered objectively to be severe since it was deeper than 120 μm.

These findings support previous concerns expressed about instructor calibration[67] and in particular offer evidence questioning the ability of calibrated instructors to accurately assess minimal or minor iatrogenic damage to the adjacent teeth, thus suggesting that student learning may benefit from efforts to improve the accuracy of such assessments either through improved calibration of instructors or possibly even more likely through the incorporation of digital technology in the process. These findings are consistent with those of other studies that highlight issues in calibration and preclinical assessment.[52,68]

Finally, although I did not articulate a predictive hypothesis related student satisfaction with the protective matrix, the satisfaction questionnaire revealed moderately high satisfaction among the students with using the protective matrix, suggesting they consider the protective matrix an effective device for protecting adjacent teeth during crown preparation. Furthermore, several students reported that interproximal reduction with the protective matrix was easier and faster because the matrix helps to keep the bur away from the adjacent tooth. However, other students reported that they tended to rely too much on the matrix, afforded by the stainless-steel barrier, for a more aggressive approach to preparation that could perforate the matrix unintentionally and inadvertently cause damage to the adjacent tooth. Other students reported that the protective matrix becomes loose after the proximal contact is initially opened, and so the need to then continue the proximal reduction without the protective matrix explains that damage may still occur even though the protective matrix was used initially.

Overall, this study finds only a modest advantage to using a protective matrix in the early stages of learning to minimize the frequency and severity of accidental damage to the adjacent teeth during full metal crown preparation. Use of the protective matrix does not completely avoid damage, and it is not clear if any reduction in the frequency and severity of damage is clinically important. Since it is also established that rates of such iatrogenic damage persist into independent practice, it can, therefore, be recommended that students at least be exposed to using a protective matrix in the early stages of learning. Although the current study does not established that exposure to a protective matrix will improve psychomotor skills learning, exposure to its use early in the learning process should help raise awareness of the issue of iatrogenic damage, and is likely to offer some protective benefit in subsequent clinical practice, perhaps particularly during the transition stage, when students begin practicing on patients, especially in cases with limited mouth opening, tongue and cheek interference, and vision restriction.

I also acknowledge that this research has limitations, including its small sample size arising from an academic class comprising just 60 students. It would thus be valuable to repeat the study with another class to increase the sample size. Also, although application of this or other protective matrices for crown preparation is likely very similar to the skills needed for using a traditional dental wedge, further study is still be needed to assess the extent to which clinicians are able to utilize the wedge optimally in this context. Another limitation of the study is its lack of data on faculty-member agreement with their subjective assessments. Furthermore, it would be valuable to track students' performance over time to compare their performance in the later learning stages, and in independent practice.

Future studies are also needed in this area to investigate possible correlations between the amount of proximal reduction and degree of proximal wall tapering during proximal preparation of the abutment tooth and the frequency and severity of damage to the adjacent teeth. Further research is still needed for better understanding of the protection mechanism behind the protective matrix. Perhaps comparing the protective matrix with a traditional dental wedge could explore the extent to which a wedge itself, without the steel matrix, may explain a portion of the protective effect potentially due to separation of the teeth simply by the wedging effect. Furthermore, additional studies should investigate the potential implementation of digital technologies as learning tools in preclinical education, which could increase students' self-assessment skills, significantly improve their performance in crown preparation in general, and minimize the potential for iatrogenic damage to adjacent teeth. The data gathered in this study may also encourage dental digital systems engineers to further develop their software for educational purposes and explore improved software features for assessing students' preparations in preclinical settings.

Chapter 6: Conclusion

Within the limitations of this study, I conclude that the frequency of iatrogenic damage to adjacent teeth during preclinical crown preparation by novice dental students working without a protective matrix is high, while usage of a protective wedge reduces the frequency and severity of iatrogenic damage to adjacent teeth.

I can also conclude that there was poor agreement between the subjective assessment and objective digital assessment of iatrogenic damage to adjacent teeth, and it would appear this is likely because faculty members are lacking the degree of depth perception possible with an objective digital assessment. Digital technology has the advantage of visualizing the adjacent surfaces at a higher magnification than that possible with conventional dental magnification loops, which makes detection of the damage easier.

Finally, the results also emphasize the critical need to raise awareness of the potential for iatrogenic damage to adjacent teeth by novice dental students and to stress the responsibility of dental educators to investigate and implement feasible approaches to prevention, including the very promising use objective digital systems for enhancing students psychomotor skills learning.

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Appendices

Appendix A. Consent Form for DMD students

UBC DENTISTRY | THE UNIVERSITY OF BRITISH COLUMBIA | DEPARTMENT OF ORAL HEALTH SCIENCES

Consent Form

Department of Oral Health Sciences
Faculty of Dentistry
2199 Wesbrook Mall
Vancouver, BC V6T 1Z3

An educational study on
"Improving approximal reduction and minimizing iatrogenic damage during crown preparation"

Principal investigator: Dr. Ross Bryant, Assistant Professor,
Department of Oral Health Sciences, Faculty of Dentistry, 604-822-2350

Co-investigator: Dr. Ahmed Ballo, Graduate Prosthodontics Student
Department of Oral Health Sciences, Faculty of Dentistry, 604-363-2897

This study is part of the MSc graduate research program for Dr. Ahmed Ballo, Prosthodontics Graduate Student, Faculty of Dentistry. Results of the study will appear in the MSc thesis and will be written up for publication in a scholarly journal and/or presented at an academic conference.

Purpose of our study: There is good evidence that the incidence of iatrogenic damage to adjacent teeth is very high during approximal preparation for prosthetic dental crowns. The purpose of this study is to assess preclinical dental student crown preparation outcomes using a protective matrix to reduce three common approximal reduction errors: over-tapering, over-reduction and iatrogenic damage to adjacent teeth.

What will happen: You are invited to participate in this study during the Restorative Dentistry II Course in the UBC DMD Curriculum. During two usual practice sessions for the #46 Full Gold Crown, as part of this course, students will be randomly assigned to undertake crown preparation practice with or without using a protective matrix (FenderWedge ®) to help isolate the tooth, followed by a crossover of the groups in the subsequence practice session. As usual the students and instructors will evaluate the preparation using a standard protocol. As usual, the student and instructor assessments during these practice sessions will not count toward formal student grades. Subsequent to these initial practice sessions all students will undertake a timed quiz for the #46 Full Gold Crown **where the instructor assessment does count toward the student's** progress as usual, and during which use of the protective matrix will be optional as usual. At each session, the students will also complete a Fenderwedge Satisfaction form. Prior to the study, as part of the usual curriculum, students will receive instruction on using the protective matrix to isolate the tooth.

Risks and benefits to you: There are no known risks for this study above the usual risks encountered learning a new surgical skill that is already being undertaken as part of the course, and the study should improve information about the value of the protective matrix for dental student performance during crown preparation. You will still have access to instructor feedback as a usual part of the course.

Confidentiality: Your participation and all information collected will be kept confidential and made available only to the investigators. You will not be identified personally in any reports of the study, and all of the assessment forms will be destroyed when the project is complete and published.

Questions: If you have any questions about the study at any time please contact Dr. Ahmed Ballo, at 604-363-2897, or e-mail at ahmed.ballo@dentistry.ubc.ca

Complaints or Concerns about the study: If you have any concerns about your rights or treatment as a research subject you may telephone the Office of Research Services at the University of British Columbia at Tel: (604) 822-8581.

Consent: Your participation in this study is entirely voluntary. You can choose to withdraw from the study at any time without consequences to your educational progress as a UBC student. You have received all the information you requested about the study and you know who you can contact if you have questions.

I acknowledge receipt of a copy of this consent form, I have had the opportunity to ask questions and have had satisfactory responses to my questions, and I consent to participate in this study.

______________________	______________________________	________________
Print Name	Participant Signature	Date
______________________	______________________________	________________
Dr. Ross Bryant	Investigator Signature	Date

Appendix B. Ethics Approval Certificate

The University of British Columbia
Office of Research Services
Behavioural Research Ethics Board
Suite 102, 6190 Agronomy Road, Vancouver, B.C. V6T 1Z3

CERTIFICATE OF APPROVAL - MINIMAL RISK

PRINCIPAL INVESTIGATOR:	INSTITUTION / DEPARTMENT:	UBC BREB NUMBER:
Stephen Ross Bryant	UBC/Dentistry/Oral Health Sciences	H17-02108

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:

Institution	Site
UBC	Vancouver (excludes UBC Hospital)

Other locations where the research will be conducted:
n/a

CO-INVESTIGATOR(S):
Ahmed M. F. Ballo

SPONSORING AGENCIES:
N/A

PROJECT TITLE:
Use of a protective matrix to improve axial reduction and minimize iatrogenic damage of adjacent teeth during crown preparation

CERTIFICATE EXPIRY DATE: January 31, 2019

DOCUMENTS INCLUDED IN THIS APPROVAL:

DATE APPROVED:
January 31, 2018

Document Name	Version	Date
Protocol:		
Research Proposal	2	January 29, 2018
Consent Forms:		
Study Consent	2	January 25, 2018
Questionnaire, Questionnaire Cover Letter, Tests:		
FenderWedge satisfaction form	N/A	December 28, 2017

The application for ethical review and the document(s) listed above have been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

This study has been approved either by the full Behavioural REB or by an authorized delegated reviewer

Appendix C. Satisfaction Questionnaire

FENDERWEDGE SATISFACTION FORM

Student Number: ____________________________ **Today's date:**

STUDENT EVALUATION OF PROTATIVE MATRIX (FENDERWEDGE)

Please evaluate your overall satisfaction using the FenderWedge

1) place an X on the line below from 0 to 100 to represent your OVERALL SATISFACTION using the FENDER WEDGE

0 ____ **100**

very unsatisfied **very satisfied**

☐ Please check here if you were NOT able to use the wedge

2) check ONLY ONE BOX on use of additional wooden wedges:

☐ I did NOT need an additional wooden wedge to stabilize the Fenderwedge
☐ I DID need an additional wooden wedge to stabilize the Fenderwedge

4) add written comments if you wish on use of the fender wedge for crown prep.

Thank you!