



Tufts
UNIVERSITY

School of
Dental Medicine

The Use of Touch Surgery to Facilitate Knowledge Retention for Dental Students:
A Randomized Controlled Trial

A Thesis

Presented to the Faculty of Tufts University School of Dental Medicine

in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Dental Research

by

Tahir Hamza

July 2021

THESIS COMMITTEE

Thesis Advisor

Irina F. Dragan, DDS, DMD, MS

Associate Professor

Director of Faculty Education and Instructional Development

Department of Periodontology

Tufts University School of Dental Medicine

Committee Members

Robert Gyurko, DDS, PhD

Associate Professor

Director of Predoctoral Periodontology

Department of Periodontology

Tufts University School of Dental Medicine

Aruna Ramesh, BDS, DMD, MS

Professor

Associate Dean for Academic Affairs

Department of Diagnostic Sciences

Tufts University School of Dental Medicine

Sarah Pagni, MPH, PhD

Assistant Professor

Division of Biostatistics and Experimental Design

Department of Public Health and Community Service

Tufts University School of Dental Medicine

Michael Newman, DDS
Professor Emeritus
Department of Periodontics
UCLA School of Dentistry

ABSTRACT

Aims & Hypothesis:

Touch Surgery (TS) is a mobile application simulator used by more than one million healthcare professionals around the world. The primary aim of this study was to evaluate knowledge retention of pre-doctoral dental students regarding the anatomy of the maxillary sinus floor and sinus elevation procedure when using the Touch Surgery (TS) mobile application (“Anatomy for maxillary sinus floor augmentation” module) compared with the traditional educational methods. The secondary aim of this study was to assess the students’ perception via semi-structured interviews regarding their experience with the TS app and its use to enhance the learning process.

We hypothesized that the use of TS app (“Anatomy for Maxillary Sinus Floor Augmentation” module) will have a positive impact on the knowledge retention (higher scores $\geq 20\%$) for pre-doctoral students as compared to traditional educational methods.

Materials & Methods: A randomized controlled trial was performed at Tufts University School of Dental Medicine (TUSDM) in a virtual setting. To achieve triangulation of the data, this study used a mixed methods design, integrating quantitative and qualitative data. Third year dental students’ participants from TUSDM were randomly allocated to either a control or test group. Control group used traditional educational methods and test group used TS app for learning anatomy of maxillary sinus floor augmentation. For the quantitative data, pre-assessment and post-assessment test assessed participants knowledge of anatomy of maxillary sinus floor augmentation. For the qualitative data, semi-structured interviews were conducted with the test group to learn from their experience using the TS app. The qualitative responses were independently coded and after identifying the main themes word clouds were

generated using nVivo software. For the quantitative data, a power calculation was performed in nQuery Advisor and a minimum sample size of 10 participants per group for a total of 20 participants was calculated. All statistical analyses were performed using SPSS Statistics Software 26.

Results: A total of 17 third year dental students at TUSDM consented to participate in this study (N=9 control group and N=8 test group). This study found that test group was able to improve (pre-assessment mean; 19.13, post-assessment mean; 20.75) as compared to control group (pre-assessment mean; 16.78, post-assessment mean; 16.67). However, the results were not statistically significant (pre-assessment p-value; 0.08, post-assessment test p-value; 0.07). For the qualitative data, during the semi-structured interviews of the test group (n=5), majority of participants reported that TS app represents an informative and engaging training tool.

Conclusions: This randomized controlled trial reports that the TS app is a comparable tool to traditional educational methods, evaluated using the knowledge retention scores. Based on the qualitative data, this tool was well received by the dental students. Academic institutions should consider integrating technology that can facilitate knowledge retention and is well received by the students. Future studies might focus on the impact of integrating this technology to improve patient care outcomes in a dental school setting.

DEDICATION

First and foremost, I would like to thank my family for their continuous support.

I would like to sincerely thank all the outstanding committee members for their guidance and support throughout this study. It was an honor to work closely with each one of them and I appreciate their precious time they devoted for this project.

In particular, I want to credit Associate Professor Dr. Irina Dragan for being an inexhaustible resource, role model, and inspiration to me.

ACKNOWLEDGMENTS

I would hereby like to compliment Dr. Britta Magnuson, Ms. Sarah Anderson, and Ms. Nicolette Kafasis for contributing significantly while working for the IRB approval of the project. I also wish to express my deepest gratitude and appreciation to the predoctoral dental students that kindly volunteered to be part of the project.

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LIST OF ABBREVIATIONS

TUSDM – Tufts University School of Dental Medicine

TS – Touch Surgery

App – Application

MCQ's – Multiple Choice Questions

MAS - Mobile Application Simulator

CTA - Cognitive Task Analysis

VR - Virtual Reality

3D - 3-dimensional

SD – Standard Deviation

NBDE - National Board Dental Examinations

The Use of Touch Surgery to Facilitate Knowledge Retention for Dental Students:
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Introduction

Literature review

Educators are considering innovative, imaginative teaching strategies to support their students' long-term preservation of knowledge. The Commission on Dental Accreditation (CODA) standards require dental education programs to use technology. It states that "Contemporary dental education programs regularly assess their use of technology and explore new applications of technological advances to enhance student learning and to assist faculty as facilitators of learning and designers of learning environments." (p. 15).¹

Teaching surgical skills using simulation has been well-documented in the medical education.² Simulators can provide a safe and structured training method without any of the risks associated with a live surgery. The advancement in the field of surgical simulation paired with the respective interactions can be engaging and interactive, fostering an environment similar to "real" surgical procedures.³ Technological advancements through the use of simulators allow clinicians to remain up to date with the improvements in surgical strategies and procedures.⁴ With the advent of sophisticated mobile technology, simulators have become less costly and more accessible. Touch Surgery (TS) is a mobile application simulator (MAS) (Figure 1) used by more than one million healthcare professionals around the world.⁵ TS app has been used in the medical field extensively. For dentistry, currently there are 4 modules available on the app (bone level implant placement, soft tissue level implant placement, connective tissue graft, and anatomy for maxillary sinus floor augmentation). In a study⁶ conducted at Tufts University School of Dental Medicine, published in Journal of Dental Education, the authors reported how this technology (TS app)

was integrated to transition clinical rotations to a virtual experience. The authors of the study tested students' knowledge retention at the beginning of the study with the help of polling questions. To give the students a step-by-step experience of a periodontal procedure, the research team used the TS app. Next the authors of the study tested students' knowledge retention with the same polling questions and reported the difference in students' knowledge retention. Despite the increased number and positive outcomes on TS in medical education, to the authors' knowledge there is a gap in the literature in terms of the value of TS app and the use of this type of technology in dental education.

TS is a London, New York City, Sydney and Auckland-based health technology app and trading name for the company Digital Surgery LTD. It is designed for smart devices (i.e., smartphones and tablets) and is available for free on Apple and Android portable smart devices. The app, founded in 2012, is a surgical simulator which provides a unique platform for surgical training, as it allows trainees to practice and rehearse surgery step by step.

The TS educational platform is supported by key basic science concepts applied to a simulated clinical environment. The TS platform is a hybrid of cognitive analysis (CTA) and Virtual Reality (VR) simulation in which trainees interact with 3-dimensional (3D) animation to rehearse a given surgery in stepwise fashion. Through this technology learners gain access to the necessary tools, anatomic landmarks, and pitfalls of the chosen surgical procedure. The ability to do each step of surgery with your own hands, as well as the detailed and comprehensive information offered in the TS app, distinguishes this technology, and makes it novel.

CTA is the method used in the TS simulations to elicit an expert understanding of what is needed to perform a complex task. CTA is "cognitive" in the sense that it attempts to

identify the mental processes and decisions that experts use to achieve a goal and/or solve a complex problem. CTA is frequently applied to understand work processes, inform the design of decision support systems, and develop ergonomically sound tools to effectively support human performance.⁷

This app has been used extensively in the medical field and there is abundant literature highlighting the impact on the knowledge retention⁸ and patient care⁹. The validation and use of the TS interactive simulator, has been reported by many independent peer-reviewed publications^{10,11} for its innovative approach to training surgeons virtually. Most of research studies that investigated the use of TS app in medical education are looking at various outcomes: knowledge retention, validation, and patient care.

There is significant evidence in the literature supporting the value of this study. Advances in mobile connectivity, enhanced mobile internet and affordability have resulted in a significant rise in medical use of smartphones.¹² For example, one study¹³ found positive expectations and overall satisfaction of the students with their experience in the use of mobile technology in medical English course. Smartphones are now an invaluable tool for easy and convenient access to information.¹⁴ Mobile solutions reflecting common clinical practices have been utilized for the exchange of knowledge in medical education and as another form of faculty development.¹⁵

The increased focus on patient safety may be the reason for decreased number of opportunities to watch and perform surgery for surgical learners. For surgery, that requires learning fine motor skills such as coordination and dexterity – reducing “hands-on-time” might have important implications for training.¹⁶

There are reports of successful approaches among the software and applications for medical education, such as the use of virtual reality for training procedures¹⁷ or the use of applications to create surgical skills.⁹

Considering the sparse evidence that is available for TS app in dentistry, a well-defined randomized controlled trial was designed at Tufts University School of Dental Medicine that will benefit the literature by providing knowledge retention outcomes. Among all the 4 modules available for dentistry, this study is focusing on the one with anatomy for maxillary sinus floor augmentation.

The module “Anatomy for maxillary sinus floor augmentation” has been previously validated for face and content validity (IRB#1909012) at Tufts University School of Dental Medicine (TUSDM). The current study will continue the previous work of the TUSDM team of educational researchers.

Aim and Hypothesis

1. Specific Aims:

The primary aim of this study was to evaluate knowledge retention of pre-doctoral dental students regarding the anatomy of the maxillary sinus floor and sinus elevation procedure when using the Touch Surgery (TS) mobile application (“Anatomy for maxillary sinus floor augmentation” module) compared with the traditional educational methods. The secondary aim of this study was to assess the students’ perception via semi-structured interviews regarding their experience with the TS app and its use to enhance the learning process.

2. Hypothesis:

We hypothesized that the use of Touch Surgery app (“Anatomy for Maxillary Sinus Floor Augmentation” module) will have a positive impact on the knowledge retention (higher scores $\geq 20\%$) for pre-doctoral students as compared to traditional educational methods.

For this study, knowledge retention is defined as the process by which new information is transferred to the students from the educational experience intervention, measured with the use of pre-assessment and post-assessment test scores.

3. Outcomes:

There were quantitative and qualitative outcomes for this study. For the quantitative outcome, students’ knowledge retention was evaluated through assessment tests. The scores achieved by the participants in each group were compared and reflected the knowledge retention (quantitative outcome). For the qualitative outcome, students’ perception was

assessed regarding the use and effectiveness of using TS app and participating in a virtual study via conducting semi-structured interviews (qualitative outcome).

Research Design

This study was approved (IRB#00001102) by the Tufts Health Sciences Institutional Review Board. Mixed method study design was used that had both quantitative and qualitative research methods to achieve triangulation by combining the quantitative and qualitative data. The study design was a randomized controlled trial of third year dental students at TUSDM, as identified in Figure 2. The study was carried out on Zoom, a cloud based-video conferencing tool. Third year dental students at TUSDM, enrolled in the DMD program, that were willing to participate were recruited for this study. Participation in the study was communicated to the students and that the study requires two hours of their time. Participation or the refusal to participate had no effect on the student's academic standing.

Once a participant agreed to participate, R 3.6.0 (a statistics program) was used to randomize whether the participants will be in the test group (TS app) or the control group (traditional educational methods). Each participant attended a pre-recorded presentation focusing on anatomy of Maxillary Sinus Floor Augmentation which was followed by a pre-assessment test (non-case-based Multiple-Choice Questions [MCQ's]/case-based MCQ's). After the presentation and pre-assessment test, subjects were divided into two groups: Test group and control group and assigned into Zoom breakout rooms accordingly.

During this time in the breakout rooms, test group participants were instructed to review both modules of the TS app individually: "learn" and "test". Control group participants were instructed to access any information regarding the anatomy of Maxillary Sinus Floor Augmentation using any of the resources available (lecture recordings, lecture slides, textbooks, google, etc.) This session was timed for 30 minutes.

After the 30 minutes time was completed (for both test and control groups), participants were reassigned from the breakout rooms to the “main Zoom virtual room”. A post-assessment test (non-case-based MCQ’s/case-based MCQ’s) was distributed to all participants.

At the end of the session, participants in the test group were invited to participate in semi-structured interviews to assess their perception regarding the TS app and participating in a virtual study (qualitative outcomes).

At the end of the session, participants in the control group interested to learn more about the TS app were offered an opportunity to review the presentation.

Materials and Methods

An e-mail was sent by one of the co-investigators (ID) to the TUSDM D'22 DMD candidates announcing the opportunity to volunteer for this particular study. The email was sent 10 days prior to the study, giving the opportunity for the dental students interested in participating to ask questions. A reminder email was sent the day before the study.

The criteria used for participant selection included the following:

Inclusion criteria

- Pre-doctoral dental students enrolled at TUSDM in their third year of their DMD program, class of 2022
- Additionally, all subjects must be in the US at the time of the meeting

Exclusion criteria

- Pre-doctoral dental students enrolled at TUSDM in the DMD Advanced Standing program
- Post-doctoral students enrolled at TUSDM
- Faculty and staff members
- Students outside of the US at the time of the meeting

Once a participant agreed to participate, R 3.6.0 (a statistics program) was used to randomize whether the participants will be in the test group (TS app) or the control group (traditional educational methods). Randomization was done prior so that test group participants could be asked to download the TS app in advance. This was done to allow time to solve any technical issues that they would have encountered in the mobile app

downloading process. Interested participants were invited to attend the virtual meeting via Zoom.

The meeting was locked once all participants joined. All participants attended a pre-recorded presentation focusing on anatomy of Maxillary Sinus Floor Augmentation which was followed by a pre-assessment test (non-case-based MCQ's/case-based MCQ's), distributed using the PollEverywhere platform, as seen in Figure 3. The participants used their Tufts ID to login into the PollEverywhere platform. The access link was shared during the Zoom session as screenshare format and was added in the chat too. The following security measures were taken; making sure all participants respond to each question as well as locking the questions after everyone had responded. After the presentation and pre-assessment test, subjects were divided into two groups: test group and control group and assigned into Zoom breakout rooms accordingly.

During this time in the breakout rooms, test group participants were given instructions to use the TS app. The subjects were not interacting with each other but rather were instructed to review both modules of the TS app individually: “learn” and “test”. In the “learn” module, participants were able to review key anatomical concepts, along with reading additional explanation at the bottom of the screen. In the “test” module participants were able to share feedback on various questions integrated in this module. The questions were different than the pre-assessment and post-assessment test. The answers for those questions are not part of this study and the data was not reviewed. This review was limited to 30 minutes.

If the subjects were assigned to the control group, they joined a breakout room with other participants who used the traditional methods of learning. They were instructed to

access any information regarding the anatomy of Maxillary Sinus Floor Augmentation using any of the resources available (lecture recordings, lecture slides, textbooks, online resources etc.) This session was timed for 30 minutes.

After the 30 minutes time was completed (for both test and control groups), participants were reassigned from the breakout rooms to the “main Zoom virtual room”. A post-assessment test (non-case-based MCQ’s/case-based MCQ’s) was distributed to all participants using PollEverywhere platform, as seen in Figure 2. The participants used their Tufts ID to login into the PollEverywhere platform. The access link was shared during the Zoom session as screenshare format and was added in the chat too.

At the end of the session, the participants in the test group were mentioned that they will receive an email if they want to participate in semi-structured interviews. At the end of the session, screen was shared with the recruitment information and participants were asked to fill in the respective Qualtrics link if they are interested to participate.

At the end of the session, participants in the control group interested to learn more about the TS app were offered an opportunity to review the presentation.

The interviews were scheduled at a different time by one of the co-investigators (TH). At the beginning of the interviews, the participants reviewed the information sheet specific for the qualitative part of the study. The interviews were individual, which followed a pre-determined script, as seen in Figure 4. It took approximately 15-20 minutes to conduct an interview and the interviews were recorded on Zoom.

The data was transcribed by the research team and then checked for accuracy. Two co-investigators (TH, ID) were involved with the qualitative analysis. The qualitative responses were independently coded. After identifying the main themes, a conflict resolution

was performed between the two researchers¹⁸ by discussing and identifying major and repeating themes. Accuracy was confirmed by utilizing triangulation, detailed evidence, and narrative technique. Trustworthiness was confirmed by involving multiple data analyzers and conducting member checking to ensure that the insights gathered from data collection (quantitative and qualitative) align with the participant's meaning-making. Based on this word clouds were generated using nVivo software.

Participants received \$50 for participation in the quantitative component and an additional \$50 for the qualitative component (semi-structured interviews), such that if someone participated in both components, they were compensated \$100.

Statistical Analysis

A power calculation was performed in nQuery Advisor with the following assumptions: a type I error of 5%, a type II error of 5%, a final mean (SD) percentage correct answers for the test group of 75 (7); a final mean (SD) percentage correct answers for the control group of 61 (9). This yielded a minimum sample size of 10 participants per group for a total of 20 participants.

For the quantitative data, descriptive statistics (counts and percentages, means and standard deviations, medians, and interquartile ranges) were calculated. The Independent Samples T-test was used to compare final scores on the assessment between the control and test groups. However, if the data was not normally distributed, Mann-Whitney U test was going to be used instead. Normality was assessed graphically and with the Kolmogorov-Smirnov test.

Seven separate analyses were done to interpret the data and understand it as much as possible. Separate analysis was done for the entire assessment test (questions 1-26). Along with that, separate sub-group analyses were done for those questions covered by TS app (questions 1-6,8-9,12-14,17-18, 20-25) and how they performed in those questions not covered by TS app (questions 7,10,11,15,16,19, 26). Additionally, four separate sub-group analyses were done to check how each participant performed in non-case-based questions (questions 1-11) and case-based questions (Case 1 [questions 12-16], Case 2 [questions 17-23], Case 3 [questions 24-26]).

P-values less than 0.05 were considered statistically significant. All analyses were performed using SPSS Software 26.

Results

A total of 17 third year dental students at TUSDM consented to participate in this study (N=9 control group and N=8 test group). Based on the number of the participants in the quantitative part of the trial, this study achieved 89% power.

When considering the entire assessment test (questions 1-26) the authors of the study found that test group was able to improve (pre-assessment mean = 19.13, post-assessment mean = 20.75) as compared to control group (pre-assessment mean = 16.78, post-assessment mean = 16.67). However, the results were not statistically significant (pre-assessment p-value = 0.08, post-assessment test p-value = 0.07), as seen in Table 1. Pre-assessment test and post-assessment test scores of test and control group participants are displayed in Figure 5 and 6. A closer analysis of how each participant performed in each question are displayed in Figure 7 and 8.

For the sub-group analysis of how participants performed in the questions covered by TS app (questions 1-6,8-9,12-14,17-18, 20-25) the research team used the Mann-Whitney U test and found the assessment scores between the test (mean = 14.88) and the control (mean = 13.56) group not to be statistically significant for the pre-assessment test (p-value = 0.25). However, these results were statistically significant for the test (mean = 17.00) and control (mean = 13.44) group for the post-assessment test (p-value = 0.02), as seen in Table 2.

To examine how each participant performed in those questions not covered by TS app (questions 7,10,11,15,16,19, 26) the authors of the study used the Mann-Whitney U test and found the assessment scores between the groups not to be significantly different for pre and post assessment tests. For both, the test group (pre-assessment test mean = 4.25, post-assessment test mean = 3.75, pre-assessment test p-value = 0.05, post-assessment test p-value

= 0.52), and for the control group (pre-assessment test mean = 3.22, post-assessment test mean = 3.22, pre-assessment test p-value = 0.05, post-assessment test p-value = 0.52), as seen in Table 3.

Mann-Whitney U test was used by the research team to investigate how each participant performed in non-case-based questions (questions 1-11) and found the assessment scores between the test (mean = 8.38) and the control (mean = 7.56) group not to be statistically significant for the pre-assessment test (p-value = 0.33). However, these results were statistically significant for the test (mean = 9.75) and control (mean = 7.44) group for the post-assessment test (p-value = 0.04), as seen in Table 4.

The authors of the study used the Mann-Whitney U test to assess how each participant performed in case-based questions [Case 1 (questions 12-16)] and found the assessment scores between the groups not to be significantly different for pre and post assessment tests. For both, the test group (pre-assessment test mean = 4.13, post-assessment test mean = 4.00, pre-assessment test p-value = 0.10, post-assessment test p-value = 0.31), and for the control group (pre-assessment test mean = 3.33, post-assessment test mean = 3.33, pre-assessment test p-value = 0.10, post-assessment test p-value = 0.31), as seen in Table 5. To examine how each participant performed in case-based questions [Case 2 (questions 17-23)] Mann-Whitney U test was used by the research team and found the assessment scores between the groups not to be significantly different for pre and post assessment tests. For both, the test group (pre-assessment test mean = 4.38, post-assessment test mean = 4.75, pre-assessment test p-value = 0.70, post-assessment test p-value = 0.57), and for the control group (pre-assessment test mean = 4.11, post-assessment test mean = 4.33, pre-assessment test p-value = 0.70, post-assessment test p-value = 0.57), as seen in

Table 6. To assess how each participant performed in case-based questions [Case 3 (questions 24-26)] the authors of the study used the Mann-Whitney U test and found the assessment scores between the groups not to be significantly different for pre and post assessment tests. For both, the test group (pre-assessment test mean = 2.25, post-assessment test mean = 2.25, pre-assessment test p-value = 0.61, post-assessment test p-value = 0.12), and for the control group (pre-assessment test mean = 1.78, post-assessment test mean = 1.56, pre-assessment test p-value = 0.61, post-assessment test p-value = 0.12), as seen in Table 7.

Five out of eight participants (test group) volunteered for the semi-structured interviews to share their experience with the TS app. Important themes mentioned by the participants were identified and were further used to generate word clouds by using nVivo software. Themes were related to include participants experience using the TS app, what did they like and dislike, was it helpful using the TS app, and how was their experience with the TS app as a virtual reality tool. Here are some examples highlighting the participants' feedback. Liked: *"the app is really good and I learned a lot"*; *"really good additional resource to put the words into an image and connect them"*; *"well, I liked how everything was thorough"*; *"I really like the photos I like the user friendly layout of the app"*; *"I liked that they had like a quiz"*; *"yeah it was my first experience obviously a really good one only have positive things to say"*. Disliked: *"in terms of things I didn't like I was hoping for it to be little bit more interactive"*; *"the one thing that I didn't like as much as some of the text was very long"*. Overall, the tool was well received by the participants based on the word clouds, as seen in Figure 9,10,11,12,13,14,15,16.

Discussion

The current study is the first virtual study that assesses the impact of using TS app in a U.S. dental institution setting and provides information regarding the students' perception about integrating this tool (TS app) in their daily practice. The current study did support the hypothesis that the use of TS app ("Anatomy for Maxillary Sinus Floor Augmentation" module) will have a positive impact on the knowledge retention (higher scores $\geq 20\%$) for pre-doctoral students as compared to traditional educational methods. Most of the studies presented in the medical field literature support the fact that TS app users perform significantly better than the control group utilizing traditional educational methods. In a randomized controlled trial¹⁹ with a control and a test group that included individuals that were enthusiastic users of the TS app, reported that the test group – scored 89.7% on simulation, compared to textbook users who scored 63.4% ($p < 0.001$). In the same study¹⁹ post-simulation questionnaires showed a significant improvement in cognitive scores for TS app users (38.6%, $p < 0.001$), as compared to nonsignificant improvement for textbook users (15.9%, $p = 0.304$). The current study supported this idea and showed difference in overall results for the test and the control group in terms of knowledge retention. However, these differences were not statistically significant (pre-assessment p -value = 0.08, post-assessment test p -value = 0.07),

Two separate analyses were done to check how each participant performed in those questions covered by TS app (questions 1-6,8-9,12-14,17-18, 20-25) and how they performed in those questions not covered by TS app (questions 7,10,11,15,16,19, 26). The results of how they performed in those questions covered by TS app showed that the assessment scores between the test and the control group were not found to be statistically significant for the

pre-assessment test (p-value = 0.25). However, these results were statistically significant for the post-assessment test (p-value = 0.02). As compared to assessment scores between groups which were not found to be significantly different for pre-assessment (p-value = 0.05) and post assessment tests (p-value = 0.52), for both, the test group and for the control group in those questions not covered by TS app. These two separate analyses confirm the hypothesis that this kind of adjunctive educational tool (TS app) improves students' knowledge retention. Our results are consistent with other study¹⁹ in the medical field reporting a significant improvement in post-simulation questionnaires in cognitive scores for TS app users.

Four separate analyses were done to check how participants performed in non-case-based questions (questions 1-11) and case-based questions (Case 1 [questions 12-16], Case 2 [questions 17-23], Case 3 [questions 24-26]). The results of how they performed in non-case-based questions (questions 1-11) showed that the assessment scores between the test and the control group were not found to be statistically significant for the pre-assessment test (p-value = 0.33). However, these results were statistically significant for the post-assessment test (p-value = 0.04). As compared to assessment scores between groups which were not found to be significantly different for pre and post assessment tests, for both, the test group and for the control group in case-based questions (Case 1 [pre-test p-value=0.10, post-test p-value=0.31], Case 2 [pre-test p-value=0.70, post-test p-value=0.57], Case 3 [pre-test p-value=0.61, post-test p-value=0.12]). This suggests that the simulation (TS app) and the learning provided at a U.S. dental institution (TUSDM) are not very different. The content covered in the TS app and the educational learning provided to students at a U.S. dental institution (TUSDM) is similar. This proposes that a student in a third world country could

use this adjunctive educational tool (TS app) and grasp the similar knowledge which is being delivered at a U.S. dental institution (TUSDM). This encourages the professors at dental institutions to use TS app as an adjunctive educational tool for learning along with the traditional educational methods.

For the qualitative outcome – semi-structured interviews of test group participants reported that TS app represents an informative and engaging training tool. Participants reported TS app to be a useful training and assessment tool to learn surgical procedures. These findings are consistent with other studies in the medical field literature. In a study²⁰, conducted at Department of General, Visceral and Transplantation Surgery at Heidelberg University, participants reported TS app to be highly useful and realistic application. Based on the results of these studies, TS app could be a valuable addition to a surgical education curriculum in U.S. dental institutions. The use of TS app could enhance surgical rehearsal for trainees and could be one way of improving surgical education in U.S. dental institution and lower the burden of faculty and surgery instructors by improving the patient care.

There were several strengths related to the current study. One of the main strengths was that triangulation was achieved by combining the quantitative and qualitative data. Another main strength was that this study was supposed to be done in-person but due to pandemic the authors of this study had to adapt and implement the study in a virtual format. An additional strength is that incorporating this technology into dental academic institutions can help with commission on dental accreditation (CODA).¹

There were some limitations related to the participants and study design of the current study. One of the limitations to be considered is missing data: one of the participant's was not consistent in answering the post-assessment test questions. Additionally, making each

participant attend a pre-recorded presentation focusing on anatomy of Maxillary Sinus Floor Augmentation before the pre-assessment test may have unnecessarily increased the pre-assessment test score in both groups (test and control), making it harder to find difference in the post-assessment test. Another limitation is that the study was not set up to collect demographics for the over-all study participants.

The study evaluated the validity and benefit of using a common surgical training application TS for smartphones and pad devices to improve pre-doctoral dental student's knowledge of the surgical anatomy of the Maxillary Sinus Floor Augmentation procedure. Knowledge of the anatomy is important to the student's understanding of the procedure's risks and their ability to develop a treatment plan. The outcomes of this study provided important data that can be used to improve the quality of patient care in a dental school setting. Students who are exposed to this learning tool might be able to make quicker and safer decisions at the point of care while performing procedures. The fact that the tool was so well received by the dental students emphasizes the fact that the dental education needs to adapt to the needs of the technology savvy generation and consider introducing new technologies in the dental setting. In a study⁶ (mentioned above), conducted at TUSDM, there were residents involved in teaching and making the transition of clinical rotations to a virtual experience by using TS app. This proposes that having this kind of technology (TS app) made it very easy to facilitate teaching not only for well versed educators like Dr. Gyurko (associate professor) but also for junior educators like Dr. Neste (resident). Based on this, it might be a good opportunity to integrate this technology in the postgraduate programs at U.S. dental academic institutions where the residents could use this type of technology to teach pre-doctoral students.

For future areas of research on this topic the research team could adapt the study design to multi-center trial or increase the study sample size by engaging all students in the class such as including third year DMD Advanced Standing program students rather than just limiting it to third year DMD candidates. Research team could also expand the study sample size by including the post-doctoral residents at TUSDM. Another interesting approach would be to partner with another U.S. dental institution and compare TUSDM with another institution. Since the students at TUSDM are in a “traditional” lecture-based curriculum, it might be interesting to conduct this study in a student population whose curriculum uses similar advanced learning technology tool such as TS app to see if there are inherent differences.

Conclusion

This randomized controlled trial reports that the TS app is a useful adjunctive educational tool to traditional educational methods, evaluated using the knowledge retention scores. Based on the qualitative data, this tool was well received by the dental students. Academic institutions should consider integrating technology that can facilitate knowledge retention and is well received by the students. Future studies might focus on the impact of integrating this technology to improve patient care outcomes in a dental school setting.

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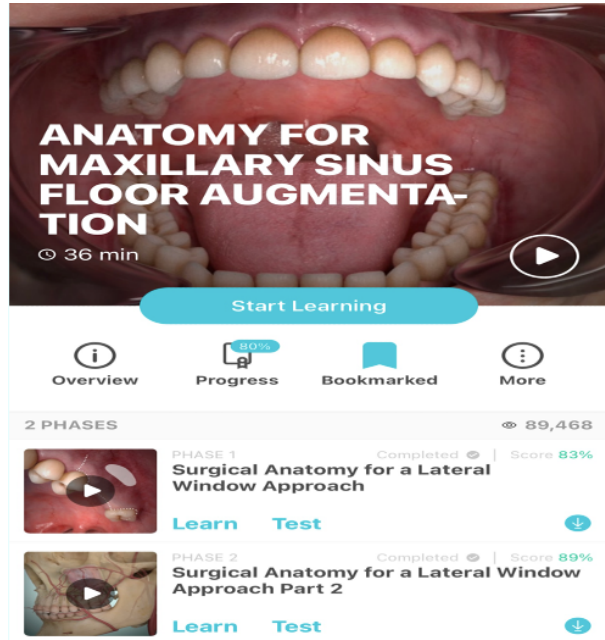
APPENDICES

Appendix A: Figures

Appendix B: Tables

Appendix C: Pre-assessment and Post-assessment Questionnaire

Appendix A: Figures



The screenshot shows the app's main interface for a specific simulation. At the top, a video thumbnail displays the title "ANATOMY FOR MAXILLARY SINUS FLOOR AUGMENTATION" and a duration of "36 min". Below the thumbnail is a "Start Learning" button. A navigation bar contains icons for "Overview", "Progress" (80%), "Bookmarked", and "More". The main content area lists two phases:

- PHASE 1**: "Surgical Anatomy for a Lateral Window Approach", marked as "Completed" with a score of 83%. It includes "Learn" and "Test" buttons and a download icon.
- PHASE 2**: "Surgical Anatomy for a Lateral Window Approach Part 2", marked as "Completed" with a score of 89%. It also includes "Learn" and "Test" buttons and a download icon.

At the bottom right of the interface, there is a "VISIT SITE" link.

Touch Surgery Interactive Surgical Simulation App

Learn, test, and prepare on more than 200 simulations.

Touch Surgery is an academically-validated interactive surgical simulator that provides a realistic and detailed guide to every step of a procedure. So you can learn, test, and rehearse for surgery – anytime, anywhere.

[VISIT SITE >](#)

Figure 1. Touch Surgery – Surgical Simulation App.

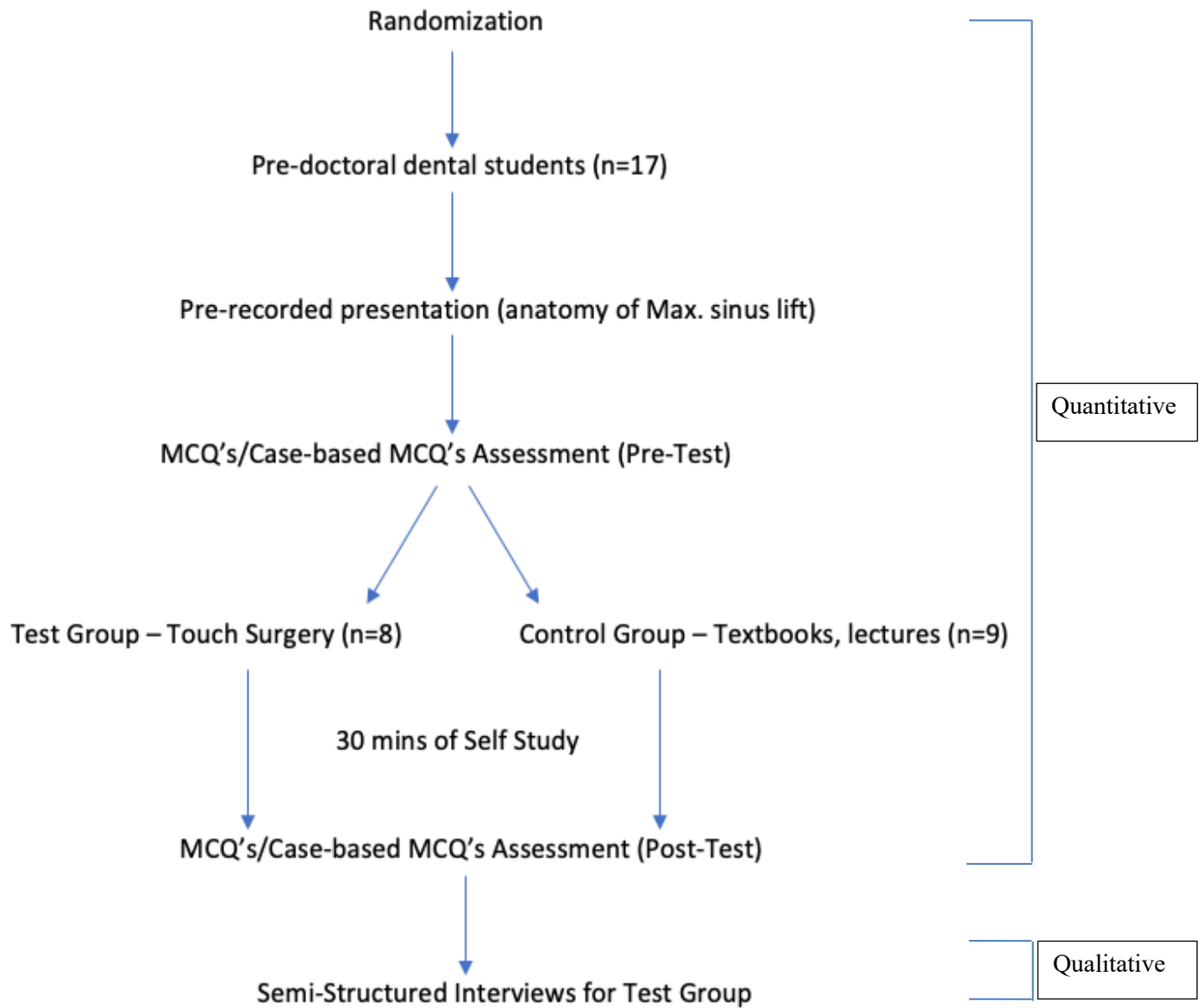
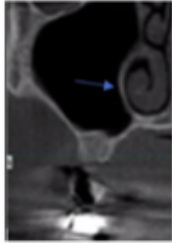


Figure 2. Schematic diagram of the proposed study design.


Respond at PollEv.com/tahirhamza400
Text **TAHIRHAMZA400** to **22333** once to join, then **A, B, C, or D**

15. When evaluating the CBCT of this patient, which wall of the maxillary sinus is represented by the blue arrow in the image below?



Anterior	A
Lateral	B
Posterior	C
Medial	D

Total Results: 1

Powered by  Poll Everywhere

Mute Stop Video Security Participants Chat Share Screen Record Live Transcript Breakout Rooms Reactions

Figure 3. Pre-assessment and post-assessment test distributed through PollEverywhere platform.

Interview:

- 1) Demographics
 - a) Demographic information: age, gender, race

- 2) Experience using Touch Surgery

First, I would like to learn about your experience using the Touch Surgery
If you were to describe your experience with the app in one or two words, how would you describe it?

 - a) What, if anything, did you like or dislike about using the app?
 - b) What are aspects of the app that can be improved?
 - c) How, if at all, was using the app helpful to you?
 - d) Based on your experience, would you recommend it to other colleagues?

- 3) Experience using Touch Surgery as a Virtual Reality Tool

Now, I would like to discuss your experience with the Touch Surgery as a reality tool

 - a. How would you describe your experiences with reality tools in general? Probe for perceived helpfulness of this type of tool

 - b. How would you describe your experience with the Touch Surgery as a reality tool compared to what you just described? Probe for perceived helpfulness of this tool

 - c. What, if any, is the role of Virtual Reality in Dental Education? Probe for students reactions to the use of VR following the participants answers.

Wrap-Up:

Before we wrap up, is there anything else you would like to add?

Thank you for taking the time out of your busy schedule to talk to me. Your feedback will help us tremendously to re-examine the use of the app to enhance our student's dental education.

Figure 4. Interview script used for conducting semi-structured interviews (qualitative part).

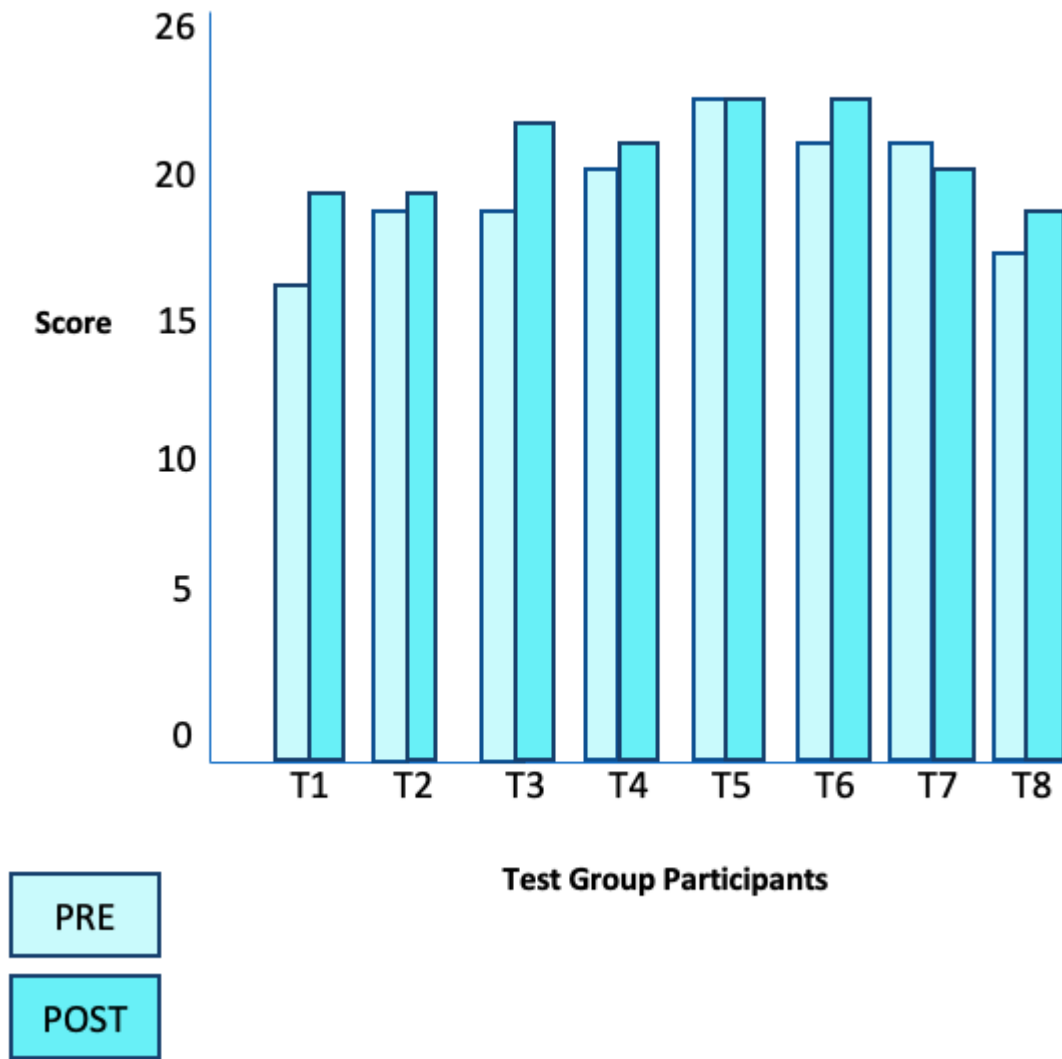


Figure 5. Pre-assessment test and post-assessment test scores of test group participants.

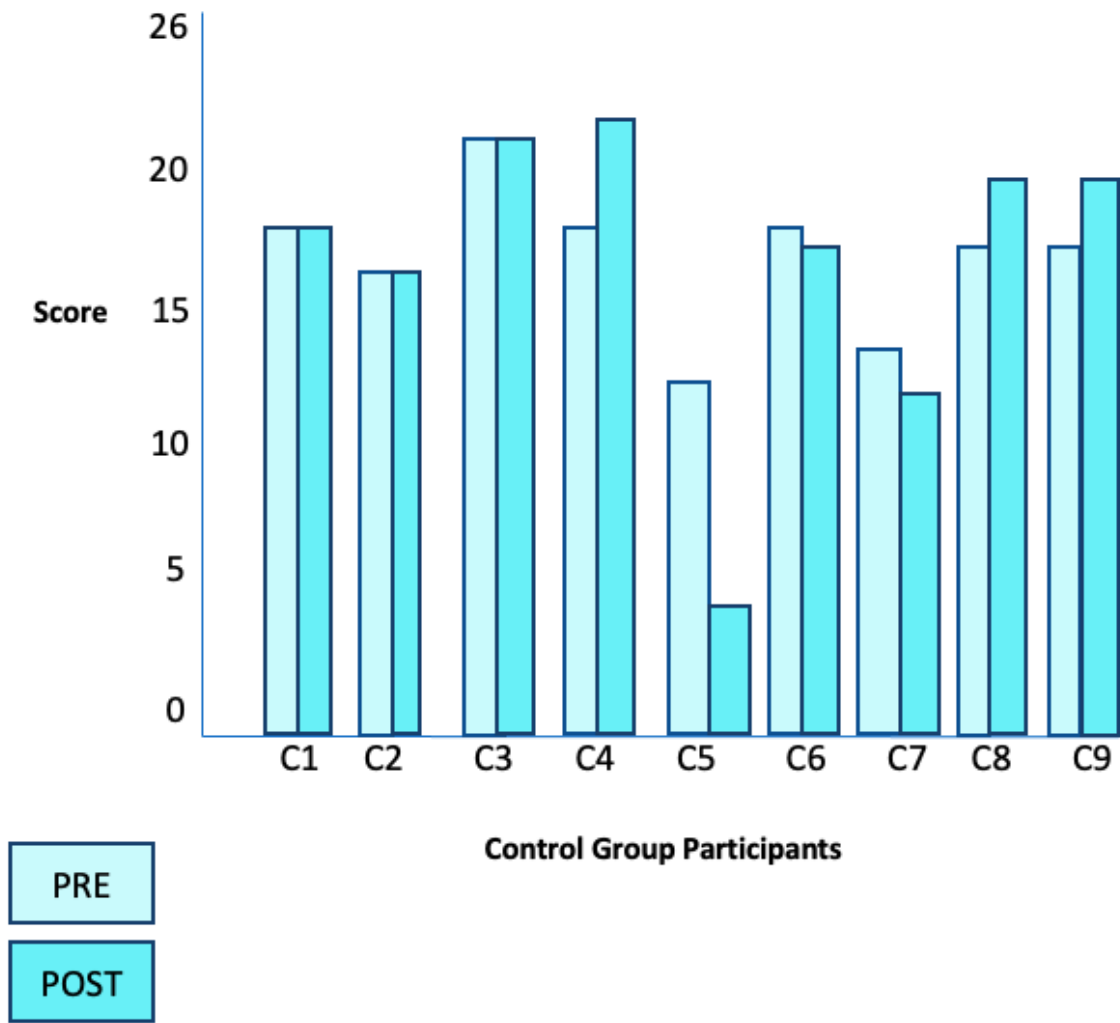


Figure 6. Pre-assessment test and post-assessment test scores of control group participants.

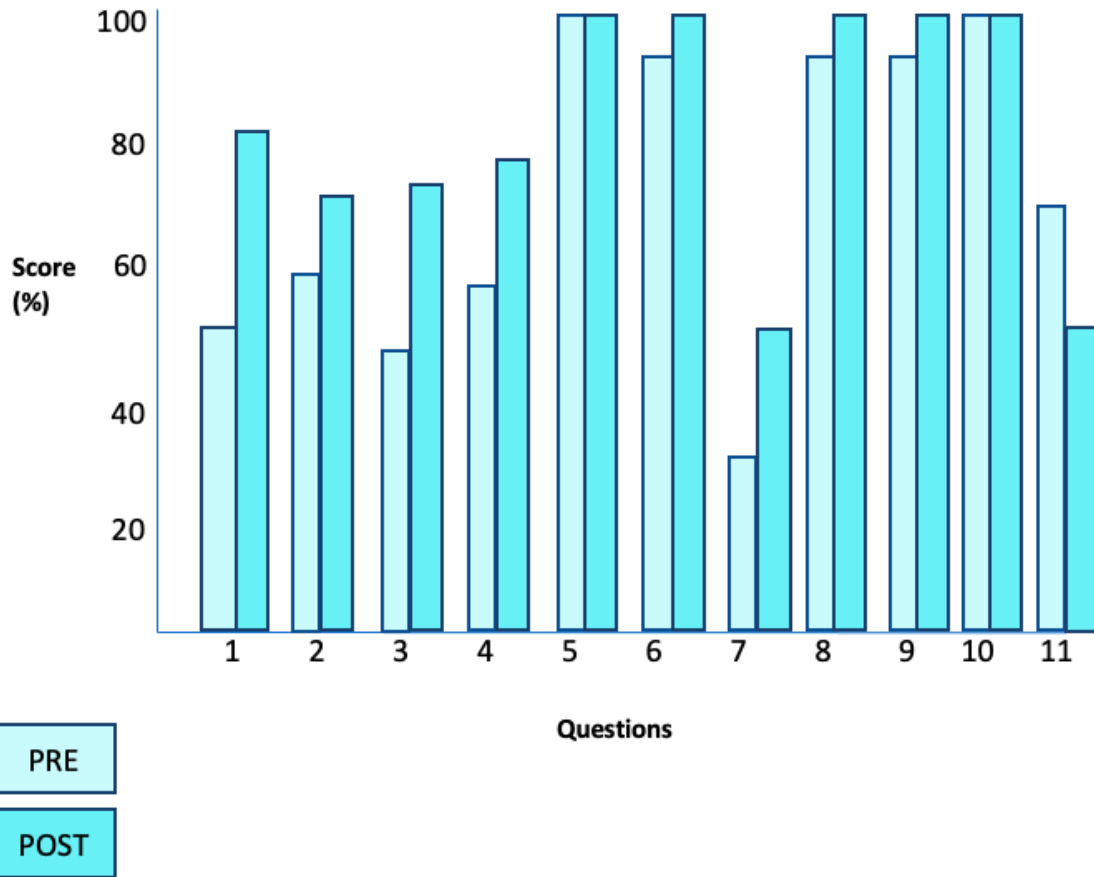


Figure 7. A closer analysis of how all participants performed in each question (case-based questions).

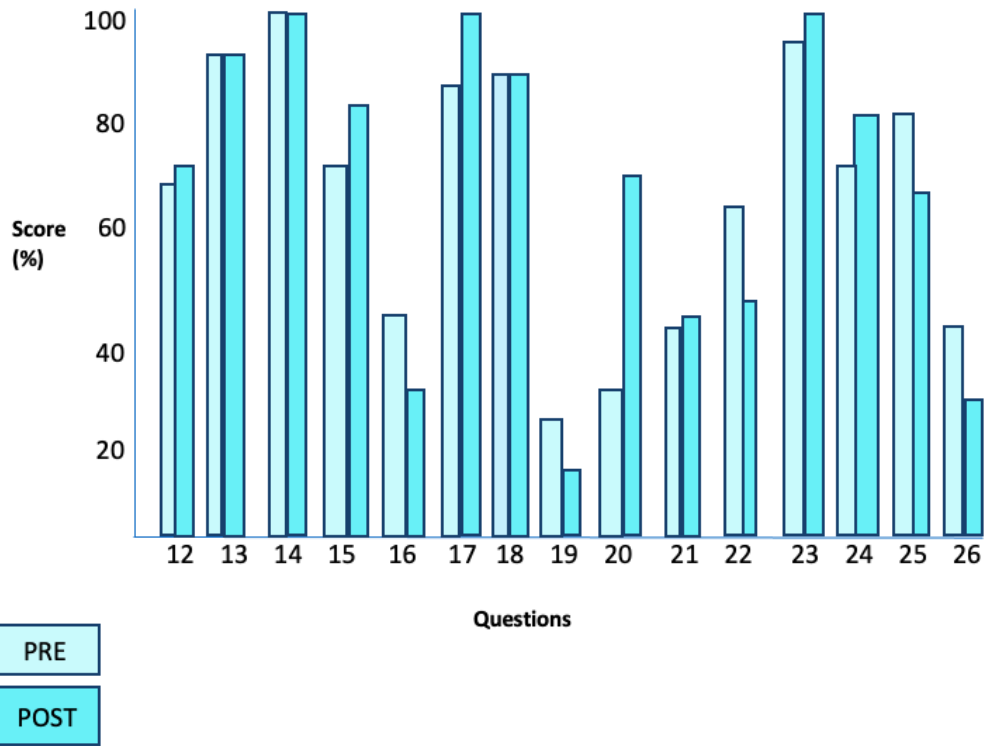


Figure 8. A closer analysis of how all participants performed in each question (non-case-based questions).

“What, if anything, did you like about using the App.”



Figure 9. Word cloud generated using nVivo software to display participant's experience.

“What, if anything, did you dislike about using the App.”



A word cloud generated from participant feedback. The words are arranged in a vertical stack, with their size corresponding to their frequency. The largest word is 'detailed', followed by 'navigation' and 'repetitive'. Other words include 'instructions', 'condensed', and 'noninteractive'.

instructions
navigation
detailed
repetitive
condensed
noninteractive

Figure 10. Word cloud generated using nVivo software to display participant’s experience.

“What are the aspects of the App that can be improved”



A word cloud visualization of responses to the question "What are the aspects of the App that can be improved". The words are arranged in a vertical stack, with the largest words at the top. The words are: navigation, condensed, description, good pictures, and instructions.

navigation
condensed
description
good pictures
instructions

Figure 11. Word cloud generated using nVivo software to display participant's experience.

“How was using the App helpful to you”



Figure 12. Word cloud generated using nVivo software to display participant’s experience

“Based on your experience with the application, would you recommend it to other colleagues.”



Figure 13. Word cloud generated using nVivo software to display participant's experience

“How would you describe your experience with Touch surgery as a reality tool.”



Figure 14. Word cloud generated using nVivo software to display participant's experience

“If you were to describe your experience with the app in one or two words, how would you describe it?”

informative
engaging
useful
interactive
intriguing helpful
easy

Figure 15. Word cloud generated using nVivo software to display participant’s experience

“What, if any, is the role of Virtual Reality in Dental Education?”



Figure 16. Word cloud generated using nVivo software to display participant's experience




Illustration 1. Photograph taken during study implementation.




Illustration 2. Photograph taken during study implementation.

Respond at PollEv.com/tahirhamza400
 Text **TAHIRHAMZA400** to **22333** once to join, then **A, B, C, or D**

16. During the clinical examination, what type of mucogingival deformity can one evaluate as shown in the image below?



Buccal-Lingual	A
Buccal-Palatal	B
Mesial-Distal	C
Cervical-Apical	D

Powered by  Poll Everywhere

Total Results: 15

Mute Stop Video Security Participants 20 Chat Share Screen Record Live Transcript Breakout Rooms Reactions

Robert Cyurko
Irina Dragan
Tahir Hamza

Illustration 3. Photograph taken during study implementation.

Appendix B: Tables

Table 1. The difference between the groups in terms of the pre- and post-assessment test for the entire assessment test (questions 1-26).

	Pre-assessment Test	
Groups	Control	Test
Mean	16.78	19.13
Standard Deviation	2.587	2.532
	Post-assessment Test	
Groups	Control	Test
Mean	16.67	20.75
Standard Deviation	5.635	1.753
p-value (pre vs. post)	0.08	0.07

Table 2. Assessment scores between groups for both pre-assessment and post-assessment in those questions covered by TS app (questions 1-6,8-9,12-14,17-18, 20-25).

	Pre-assessment Test	
Groups	Control	Test
Mean	13.56	14.88
Standard Deviation	2.603	2.031
Median	14.00	15.50
Interquartile Range	3	4
	Post-assessment Test	
Groups	Control	Test
Mean	13.44	17.00
Standard Deviation	4.362	1.069
Median	15.00	17.00
Interquartile Range	5	2
p-value (pre vs. post)	0.25	0.02

Table 3. Assessment scores between groups for both pre-assessment and post-assessment in those questions not covered by TS app (questions 7,10,11,15,16,19, 26).

	Pre-assessment Test	
Groups	Control	Test
Mean	3.22	4.25
Standard Deviation	1.716	0.886
Median	3.00	4.00
Interquartile Range	2	1
	Post-assessment Test	
Groups	Control	Test
Mean	3.22	3.75
Standard Deviation	2.048	1.165
Median	4.00	3.50
Interquartile Range	3	2
p-value (pre vs. post)	0.05	0.52

Table 4. Assessment scores between groups for both pre-assessment and post-assessment in non-case-based questions (questions 1-11).

	Pre-assessment Test	
Groups	Control	Test
Mean	7.56	8.38
Standard Deviation	0.882	1.768
Median	7.00	8.00
Interquartile Range	2	3
	Post-assessment Test	
Groups	Control	Test
Mean	7.44	9.75
Standard Deviation	3.046	1.282
Median	8.00	10.00
Interquartile Range	2	3
p-value (pre vs. post)	0.33	0.04

Table 5. Assessment scores between groups for both pre-assessment and post-assessment in Case 1 (questions 12-16).

	Pre-assessment Test	
Groups	Control	Test
Mean	3.33	4.13
Standard Deviation	1.000	0.641
Median	3.00	4.00
Interquartile Range	2	1
	Post-assessment Test	
Groups	Control	Test
Mean	3.33	4.00
Standard Deviation	1.323	1.069
Median	3.00	4.00
Interquartile Range	2	2
p-value (pre vs. post)	0.10	0.31

Table 6. Assessment scores between groups for both pre-assessment and post-assessment in Case 2 (questions 17-23).

	Pre-assessment Test	
Groups	Control	Test
Mean	4.11	4.38
Standard Deviation	1.364	1.302
Median	4.00	4.50
Interquartile Range	1	3
	Post-assessment Test	
Groups	Control	Test
Mean	4.33	4.75
Standard Deviation	1.500	1.282
Median	4.00	5.00
Interquartile Range	2	3
p-value (pre vs. post)	0.70	0.57

Table 7. Assessment scores between groups for both pre-assessment and post-assessment in Case 3 (questions 24-26).

	Pre-assessment Test	
Groups	Control	Test
Mean	1.78	2.25
Standard Deviation	1.093	0.463
Median	2.00	2.00
Interquartile Range	2	1
	Post-assessment Test	
Groups	Control	Test
Mean	1.56	2.25
Standard Deviation	0.726	0.707
Median	2.00	2.00
Interquartile Range	1	1
p-value (pre vs. post)	0.61	0.12

Appendix C: Pre-assessment and Post-assessment Questionnaire

Non-case-based questions (questions 1-11)

1. What is the average thickness (mm) of a healthy Schneiderian sinus membrane?
 - A. ≤ 0.9
 - B. 1-1.4
 - C. 1.5-2
 - D. 2.5-3

2. What is the incidence of the maxillary sinus septum?
 - A. 1%
 - B. 3%
 - C. 10%
 - D. 30%

3. Which artery is most likely to be affected when performing the lateral bony window step of the maxillary sinus elevation procedure?
 - A. Facial artery
 - B. Infraorbital artery
 - C. Maxillary artery
 - D. Superior alveolar artery

4. Select the definition for sinus pneumatization:
 - A. Communication between the maxillary sinus and the nasal cavity
 - B. Enlargement of the sinus cavity after previous tooth extraction
 - C. Perforation of the sinus membrane during the sinus lift procedure
 - D. Thickening of sinus membrane due to inflammation

5. The origin of an allograft bone is:
 - A. Animal bone
 - B. Human donor bone
 - C. Patient's own bone
 - D. Synthetic bone

6. What is the most appropriate next step if the Schneiderian membrane is perforated during a lateral window sinus lift?
- A. Abort the procedure and postpone sinus lift
 - B. Place collagen membrane over the perforation
 - C. Proceed with placement of bone graft
 - D. Suture the perforation
7. Select the characteristic that during treatment planning would suggest better outcomes related to the crestal sinus approach compared to the lateral window sinus lift:
- A. Need for better visibility during surgery
 - B. Anticipated greater amount of vertical bone gain
 - C. Less than 5mm native bone present
 - D. Limited surgical area
8. What type of epithelium is the Schneiderian membrane?
- A. Neurosensory
 - B. Pigmented
 - C. Pseudostratified Columnar
 - D. Stratified Cuboidal
9. Select the statement characteristic of xenograft bone graft material:
- A. Xenon material, in particulate form
 - B. Graft from the patient, taken from another site
 - C. Graft from another human being
 - D. Graft from another species that is not human
10. All of the following are potential risk factors for implant failure, EXCEPT ONE. Which is THE EXCEPTION?
- A. Smoking
 - B. Poor oral hygiene
 - C. Age
 - D. History of periodontitis
11. What is the appropriate time to consider implant placement after the maxillary sinus augmentation procedure has been completed?
- A. 1 month
 - B. 3 months
 - C. 6 months
 - D. 12 months

Case-based questions - Case 1 (questions 12-16)

65 years old male presented to Tufts University School of Dental medicine with the chief complaint “I want to be able to eat with my back teeth. I know I need implants.”

NOTE: The following questions will focus on the anatomy and morphology of the maxillary sinus.

12. All of the following statements are true regarding the boundaries of the maxillary sinus, EXCEPT ONE. Which one is THE EXCEPTION?
 - A. The orbital floor forms the roof of the sinus
 - B. The alveolar bone that holds the posterior maxillary teeth forms the sinus floor
 - C. The pyramidal apex of the maxillary sinus extends laterally towards the Mastoid process
 - D. Base of the sinus forms the inferior part of the lateral nasal cavity wall

13. All of the following are processes of maxillary bone, EXCEPT ONE. Which one is THE EXCEPTION?
 - A. Hyoid
 - B. Palatine
 - C. Zygomatic
 - D. Alveolar

14. Select the statement pertinent to Cone Beam Computed Tomography (CBCT):
 - A. Provides limited information for the proposed treatment site
 - B. Allows for an accurate determination of vital anatomic structures
 - C. Has good contrast resolution
 - D. Shows no artifacts

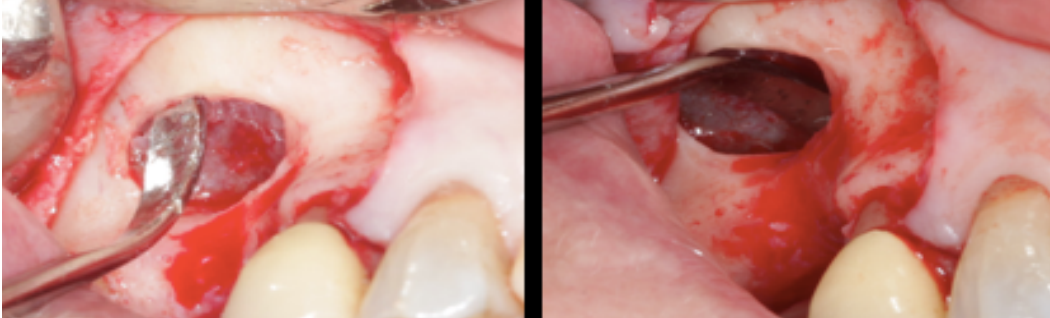
15. When evaluating the CBCT of this patient, which wall of the maxillary sinus is represented by the blue arrow in the image below?
 - A. Anterior
 - B. Lateral
 - C. Posterior
 - D. Medial

16. During the clinical examination, what type of mucogingival deformity can one evaluate as shown in the image below?
 - A. Buccal-Lingual

- B. Buccal-Palatal
- C. Mesial-Distal
- D. Cervical-Apical

Case-based questions - Case 2 (questions 17-23)

NOTE: The following questions will focus on key concepts during the maxillary sinus augmentation intra-operative procedure.

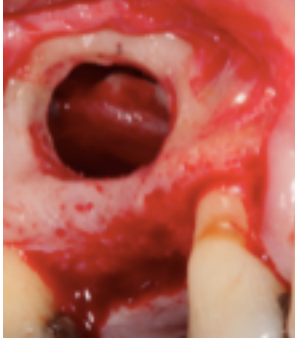


17. Select the correct order of the steps for a lateral window sinus lift procedure.
- A. Mucoperiosteal flap elevation -> Lateral window creation -> Bone graft material -> Membrane elevation -> Suturing
 - B. Mucoperiosteal flap elevation -> Lateral window creation -> Membrane elevation -> Bone Graft placement -> Suturing
 - C. Mucoperiosteal flap elevation -> Membrane elevation -> Lateral window creation -> Bone graft placement -> Suturing
 - D. Mucoperiosteal flap elevation -> Membrane elevation -> Bone graft placement -> Lateral window creation -> Suturing
18. The lateral window technique is indicated if the initial alveolar bone height is:
- A. 10mm
 - B. 8mm
 - C. 6mm
 - D. 4mm
19. What is the wall that is most commonly missed during the elevation of the Schneiderian membrane?
- A. Anterior
 - B. Lateral
 - C. Medial
 - D. Posterior

20. What is the preferred instrument to create the lateral bony window?
- A. High speed handpiece
 - B. Ultrasonic scaler
 - C. Slow speed handpiece
 - D. Piezo scaler
21. What is the preferred instrument to elevate the Schneiderian membrane?
- A. Periosteal elevator
 - B. Beaver tail
 - C. Periodontal probe
 - D. Gracey curette
22. All of the following are correct statements regarding maxillary sinus elevation, EXCEPT ONE. Which one is THE EXCEPTION?
- A. External sinus lift is also referred to as the *Caldwell approach*.
 - B. If the residual alveolar bone height is 1-3mm, a lateral approach with grafting material and delayed implant positioning is the best treatment option
 - C. The main difference between the internal and external sinus lift techniques is the area of access for the elevation of the Schneiderian membrane
 - D. Allografts, xenografts, and alloplasts provide faster resorption when compared with autogenous bone
23. After completing the elevation of the Schneiderian membrane, it is important to confirm the absence of any perforation by using:
- A. Nose-blowing test (Valsalva test)
 - B. Spirometry test
 - C. Sweat test
 - D. Saliva test

Case-based questions - Case 3 (questions 24-26)

NOTE: The following questions will focus on complications encountered during the maxillary sinus augmentation procedure.



24. The most frequent intra-operative complication during the maxillary sinus augmentation procedure is?
- A. Gingival flap tear
 - B. Schneiderian membrane perforation
 - C. Hematoma
 - D. Bony sequestrum formation
25. The most common reason for Schneiderian membrane tearing during the lateral approach technique is:
- A. Absence of alveolar bone
 - B. Bone graft material overfill with insufficient elevation of the membrane
 - C. Previous sinus surgery
 - D. Irregularities of the maxillary sinus floor/ presence of septum
26. If the perforation of the Schneiderian membrane is $<2\text{mm}$, what is the most common treatment option?
- A. The perforated sinus membrane can be sealed and repaired with a resorbable collagen membrane to repair laceration
 - B. Loma Linda pouch technique
 - C. May not require specific treatment and may resolve simply by membrane fold-over or coagulum formation
 - D. It may be best to abort the surgical procedure and reenter after 3-4 months to allow for the healing of the perforation