CBCT-Based 3D-Printed Simulation Model for Pediatric Dental Trauma Training

Anthony Leisure

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Committee:

Thomas Tanbonliong

Simon Lin

Avina Paranjpe

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Abstract

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Anthony Leisure

Co-Chairs of the Supervisory Committee:

Thomas Tanbonliong

Department of Pediatric Dentistry

Simon Lin

Department of Pediatric Dentistry

Pediatric traumatic dental injuries require immediate, evidence-based treatment to avoid long-term consequences such as pulp necrosis, root resorption, ankyloses, and loss of teeth. Despite their clinical relevance for the early management of traumatic events, many dental students do not receive sufficient practical experience of managing these high-risk situations, resulting in a wide gap between academic knowledge and clinical competence. This study aimed at developing and testing a high-fidelity, CBCT-based, 3D printed simulation model for teaching dental students dental trauma management. A CBCT scan from an 11-year-old- pediatric patient was digitized, segmented, and modified to create a three-dimensional digital model of a pediatric maxilla. The model incorporated an avulsed permanent incisor, a complicated crown fracture and built-in channels that allowed simulated bleeding from both the socket and pulp exposure. During the simulation, students performed tooth replantation, Cvek pulpotomy, and flexible splinting. Twenty-five third- and fourth-year dental students participated in a one-time group-based pre-test-post-test educational intervention. Students completed pre-and post-simulation evaluations assessing their trauma-related knowledge, confidence and preparedness. Objective knowledge proficiency was determined through case-based questions and procedural accuracy was evaluated before the simulation using a competency rubric. After completing the simulation, students provided ratings on the realism, educational value, stress level and fidelity of the model. Students demonstrated statistically significant gains in all knowledge and confidence domains after participating in the simulation. Statistically significant improvement included protocol knowledge (by 5.2 points [95% CI: 4.4–6.0; $p < 0.001$]), trauma management confidence (by 5.0 points [95% CI: 4.1–5.8; $p < 0.001$]) and bleeding control (by 4.5 points [95% CI: 3.6–5.3; $p < 0.001$]). Statistically significant objective gains occurred primarily in areas where they had shown deficits in pre-simulation knowledge. Additionally, the students rated the model highly in terms of realism, recommendation, engagement, and preference to lecture-based learning (with several median scores being 10). In addition, the students rated simulated bleeding, replantation, splinting, and Cvek pulpotomy elements very highly, supporting the model's procedural and technical fidelity. Prior to structured instruction or repetitive practice, baseline procedural accuracy was found to be moderate with a mean score of 67.2% ± 8.4%. This indicates that students did not possess full procedural competence prior to receiving instructional or practicing repeatedly. This study demonstrated that a CBCT-based, 3D-printed pediatric dental trauma simulation model can enhance students' knowledge and confidence regarding managing pediatric dental trauma. Furthermore, the study identified significant baseline deficiencies in students applied procedural skills. The model received positive perceptions in terms of its realism,

engagement, and value as an educational tool, which supports its use as a teaching tool and an evaluation instrument.

Table of Contents

I. INTRODUCTION

II. METHODS

III. RESULTS

IV. DISCUSSION

V. CONCLUSIONS

VI. FIGURES AND TABLES

VII. APPENDIX

VIII. REFERENCES

I. INTRODUCTION

Traumatic dental injuries (TDIs) are a major and widespread dental health problem. TDIs affect people of all ages, but children and adolescent populations are especially affected. The prevalence of TDIs is estimated to be as high as one-third of the world's population[4,24], and the majority of injuries occur in young children and teenagers. The high-risk behavior of children and teenagers, coupled with developing motor coordination and increased physical activity, contributes to the higher incidence rates in younger populations[4,5,6,14]. TDIs are associated with a variety of short-term and long-term complications, including pulp necrosis in immature permanent teeth. If the nerve supply to an immature permanent tooth is disrupted, it can cause arrested root development leading to incompletely formed apices[6,7]. Immature permanent teeth that have undergone arrested root development are structurally weakened, prone to fracture and have more complex endodontic challenges than mature permanent teeth. In addition to pulp necrosis and arrested root development, other complications include inflammatory root resorption, ankylosis and eventually tooth loss[7,9]. These complications emphasize the necessity of prompt and proper intervention.

Dentists face unique challenges when treating TDIs because of the rapidly changing nature of craniofacial growth and dental development in children. Because immature permanent teeth require the preservation of vital pulp to continue root maturation and apexogenesis, decisions regarding the extent of pulp removal and the use of various therapeutic modalities must be made carefully. Several studies have documented the efficacy of procedures like the Cvek partial pulpotomy as successful treatments for complicated crown fractures in children when completed correctly and promptly[10]. Success in these situations depends greatly upon an accurate diagnosis, adherence to evidence-based recommendations, and proper technical execution. Recent publications from the International Association of Dental Traumatology (IADT) provided a framework for clinicians to follow in order to maximize outcomes for patients suffering from TDIs[7,8]. The IADT emphasizes the importance of prompt and guideline-directed care after a TDI[7,8]. For example, if a permanent tooth is avulsed, the length of time the tooth is out of the alveolus (extra-alveolar dry time) and how it is stored affects the likelihood of preserving the periodontal ligament (PDL) and achieving optimal long-term results[8]. Failure to properly treat avulsions or deviate from recommended guidelines can result in replacement resorption and/or ankylosis with resultant poor or no tooth survival.

Despite the substantial body of literature documenting the severity of TDIs, the existence of standardized treatment guidelines, and ongoing efforts to educate dental professionals about the consequences of TDIs and the recommended treatment options, there continues to exist a wide gap between what is theoretically known about managing TDIs and what dental trainees and practicing clinicians apply clinically[2,3]. This "knowledge-to-action" gap is apparent in emergency situations where decision making occurs quickly, where procedural competence is crucial, and where feelings of confidence under pressure are necessary. Historically, traditional dental education programs place heavy reliance on didactics with limited opportunities for clinical exposure to trauma cases. Additionally, TDIs are naturally unpredictable and occur infrequently in structured clinical training environments. As a result, many dental students and new clinicians feel inadequately prepared to manage TDIs in clinical settings[1,2,3]. Although this inadequate preparation is not solely due to a lack of confidence, it may adversely influence patient outcomes through treatment delays, misdiagnoses, or incorrect applications of established guidelines can negatively influence patient outcomes.

Simulation-based education provides an alternative approach to addressing these shortcomings by creating a controlled, reproducible environment that allows learners to develop both cognitive and procedural skills[2,3,9]. High-fidelity simulation is designed to create a clinical environment that simulates reality in terms of anatomy and contextually relevant elements that elicit cognitive, emotional and physiological responses from learners. Notably, these include anatomical accuracy, as well as inclusion of relevant contextual elements such as time pressures, visual cues, procedural complexity etc[1,2]. Educational frameworks that incorporate interdisciplinary problem-based learning further increase the efficacy of simulations by increasing learner engagement through active participation, fostering critical thinking through case-based learning and integrating knowledge across multiple disciplines. Simulation provides pediatric dental educators with an opportunity to create an environment that exposes learners to high stakes pediatric dental trauma cases that they would likely see few times during their clinical rotations[1].

While many current simulation models utilized in dental education lack sufficient realism or fail to reproduce the full scope of clinical and emotional factors present during trauma scenarios, many are limited to reproducing individual procedural steps rather than simulating comprehensive case management involving diagnosis, treatment planning and executing treatment in a realistic manner. Additionally, while there exists some literature assessing not only the knowledge acquisition and self-assessment of confidence by learners who complete simulation experiences but also objective measures of learner clinical performance during simulation and physiological stress response during simulation[2,3,25], little attention has been paid to understanding how perceived competency relates to actual procedural competency.

Importantly, excessive confidence without adequate skill proficiency could be detrimental to patient safety.

Given these gaps in current simulation models for pediatric dental trauma management there clearly is a need for the development and evaluation of high-fidelity standardized simulation models that accurately recreate pediatric dental trauma scenarios in order to assess learner outcomes comprehensively. Using 3D printing technology combined with advanced imaging technologies such as cone beam computed tomography (CBCT) enable researchers to create anatomically accurate models of real patient data. When combined with modifications to produce models that replicate injury patterns (e.g., avulsion, complicated crown fractures that require Cvek pulpotomy, splinting procedures) these models offer unparalleled clinical realism. Incorporating soft tissue analogs with simulated bleeding will help create an immersive experience that may evoke physiological stress responses similar to those experienced in actual clinical settings. Thus, the goal of this study was to develop and evaluate a CBCT-derived 3D printed high fidelity simulation model for pediatric dental trauma management.

II. METHODS

Study Design

This study employed a prospective single group pre-test/post-test educational intervention design to evaluate the efficacy of a simulation-based training model for pediatric dental trauma management. Because there is no control group, this study focused on within-subject differences before and after completion of a single simulation exercise.

Subjects

Subjects consisted of third- and fourth-year dental students attending the University of Washington School of Dentistry. A target sample size of approximately 25 participants was determined based on power calculations indicating that 25 participants would yield 80% statistical power to detect moderate effect sizes (d = 0.5-0.6) utilizing paired comparison methodology at an alpha level of 0.05.

All simulation-related activities were conducted within the Center for Pediatric Dentistry Clinical Training Environment to facilitate familiarity with the clinical environment common for pediatric dental care delivery.

Eligibility criteria included current enrollment as a D3 or D4 student at the University of Washington School of Dentistry and willingness to complete both pre-and post-simulation surveys. Participant demographics, including age, gender, years of pediatric clinical experience, and previous exposure to trauma cases were recorded to contextualize findings.

Development of Simulation Model

Acquisition/Segmentation of CBCT Images

A CBCT scan obtained from an 11-year-old pediatric patient served as the basis for model development. The scan was acquired using a Vatech PHT-35LHS CBCT unit (Vatech Co., Ltd., Gyeonggi-do, Korea). DICOM images were imported into Mimics version 26 (Materialise NV., Leuven, Belgium) for segmentation purposes. Bone masks were created using a threshold-based segmentation followed by manual contouring to define individual teeth and maxillary structures, allowing precise anatomical reproduction.

Modification of Digital Anatomical Models

Anatomical structures segmented from DICOM images were then converted into STL files and imported into Materialise 3-Matic software version 18 (Materialise NV, Leuven, Belgium). The digital model was then modified to include clinically relevant injury patterns including:

- A removable central incisor representing an avulsed central incisor

- A simulated crown fracture of central incisor with pulpal exposure
- Simulated gingiva representing a 2-mm gingival layer around maxillary arch
- An internally embedded fluid channel extending from posterior inlet to the apical openings of the central incisors, allowing artificial blood to pass through and simulate bleeding
- A Solid base designed to facilitate attachment to the dental chair during simulation

These design features were intended to reproduce both hard- and soft-tissue responses during trauma-related interventions.

Fabrication/Properties of Materials Used for Printing

Following digital modification, the final models were fabricated using a Stratasys J750 PolyJet 3D Printer (Stratasys Ltd., Rehovot, Israel) with materials selected to replicate the mechanical and tactile characteristics of hard and soft tissues. Vero White was used to fabricate the maxillary bone and tooth structures, while Agilus 70A shore hardness in magenta was used to fabricate the gingiva to mimic soft-tissue elasticity and resilience. Multimaterial printing enabled a high-fidelity simulation model with distinct tactile properties between hard- and soft-tissue components.

Simulation Intervention Protocol

Participating students completed a single simulation experience lasting approximately 30-45 minutes, during which they managed a standardized pediatric dental trauma scenario. The simulation included two concurrent injury presentations: an avulsed permanent incisor and a complicated crown fracture of a permanent incisor with pulpal exposure. Students were expected to perform the following procedures:

- Handle the avulsed tooth appropriately
- Replant the tooth into the socket
- Place a flexible splint
- Manage a complicated crown fracture with pulpal exposure
- Perform a Cvek Partial Pulpotomy
- Achieve Hemostasis
- Apply an appropriate pulp medicament
- Restore the fractured tooth

During each step, an observer evaluated participant performance using a standardized competency rubric to ensure consistent assessment.

Data Collection and Measurement Tools

Surveys

Three measurement periods occurred during this study:

Pre-Simulation Survey: Baseline measurements were taken to assess:

Knowledge regarding management of traumatic dental injuries

Self-Assessment Confidence and Clinical Skills

Readiness and Emergency Situations

Post-Simulation Survey: Same questions as above were reassessed immediately following simulation experience

Model Evaluation Survey: Assesses:

Simulation Realism

Educational Value

Stress Levels

Engagement During Simulation

Effectiveness Compared to Traditional Learning Methods

Confidence and Preparedness were assessed using a 0-10 Likert Scale:

0 = No Confidence at All

10 = Extremely Confident

Knowledge Assessments were case-specific clinical scenarios:

Management Avulsion Injury in Immature Permanent Teeth

Technique Indication Cvek Pulpotomy

Outcomes Measures

Primary Outcome Measures

Changes from Pre-Simulation Scores vs Post-Simulation Scores in Knowledge Regarding Management of Traumatic Dental Injuries

Changes from Pre-Simulation Scores vs Post-Simulation Scores in Self-Assessed Confidence and Preparedness Regarding Managing Traumatic Dental Injuries

Secondary Outcome Measures

Objective Clinical Performance Procedural Competency Scores Based Upon Rubrics Utilized to Evaluate Participants During Simulations

Simulation Realism and Educational Value Ratings

Physiological Stress and Stress Response Levels During Simulation

Clinical Competence Evaluation

Participant performance during simulation was evaluated based upon participant executions using a rubric across four areas:

- Replantation Technique
- Cvek Pulpotomy Technique Execution
- Quality Restoration
- Accuracy Splint Creation
- Case Management Total

Rubric scores were categorized based on Quality of Performance (Satisfactory Needs Improvement Unsatisfactory); thus, each participant received a cumulative competency rating.

Statistical Analysis

Descriptive statistics were used to report on the participant's demographics and study results. For continuous variables (age, confidence, knowledge, model assessment and procedure accuracy), we calculated the mean and standard deviation. We also calculated median, quartiles, range, and skewness to provide information about the shape of the response. We described the categorical variables (gender, year in dental school, prior pediatric experience, prior trauma experience) through frequency and percentage.

To assess the pre-and post-simulation performance of participants in the areas of confidence and knowledge, we calculated change scores by subtracting the pre-simulation score from the post-simulation score. To assess if there is an asymmetry in the distribution of each change score, we calculated skewness. Since the distributions of the change scores are approximate symmetrical, we employed a paired t-test to assess if the average post-simulation performance differs statistically from the pre-simulation performance. We reported the average difference along with 95% CI to indicate both the direction and degree of improvement seen in this area.

The case-based knowledge questions were examined as paired binary data; the responses were coded as either "correct" or "incorrect" before and after the simulation. As these represent paired categorical data from the same subjects, we applied McNemar's Exact Test to assess if there has been a significant increase in correct answers from before to after the simulation. In addition to reporting the differences in percent correct, we provided exact 95% CI for each variable.

We used descriptive statistics (means, SDs, medians, IQRs, Ranges, Skewness) to characterize subject feedback regarding the simulation model (realism, engagement, stress, educational value, bleeding during simulation, replantation during simulation, splinting during simulation, Cvek pulpotomy specific outcomes) and subject ratings of procedure accuracy. We set our alpha level at $p = .05$. Due to the limited number of participants in this study, we focused on describing the magnitude of change as well as providing confidence interval estimates of that change.

Ethical Considerations

This study was conducted in accordance with institutional ethical standards. Participation was voluntary, and all data were de-identified prior to analysis to ensure confidentiality. This study was approved by The University of Washington IRB (STUDY00022864).

III. RESULTS

Participant Characteristics

Twenty-five dental students completed the study. Participants had a mean age of 28.2 ± 4.9 years, with a median age of 27.0 years (interquartile range [IQR]: 25.0–29.0). The ages of participants varied from 24 to 40 years and exhibited slight positive skewness. There were predominantly females (92%) in the participant group, and the majority of the participants were third-year students (84%). Fourth-year students made up a small percentage of the participants (16%).

The participants reported varying amounts of previous pediatric and trauma-related clinical exposure. Although 76% of the participants indicated limited to moderate experience in pediatric dentistry, there was very little experience related to trauma among participants, with 76% indicating "no" or "limited" experience in managing traumatic dental injuries (Table 1).

The demographic data indicate that the participants represent a cohort of early clinical learners who lack extensive direct experience in the treatment of traumatic dental injuries.

Improvements in Knowledge and Self-Esteem Changes

Descriptive Findings

Following participation in the simulation program, participants' knowledge and confidence in all measured areas significantly improved.

Pre- and Post-Simulation Confidence Means

Post-simulation confidence in trauma management increased from 3.6 ± 2.0 pre-simulation to 8.6 ± 1.0 post-simulation, representing a mean increase of 5.0 ± 2.1. Pre- and post-simulation confidence in bleeding control also increased from 4.1 ± 2.3 to 8.6 ± 1.0, resulting in a mean increase of 4.5 ± 2.0. Confidence in protocol knowledge was the greatest area of improvement, increasing from 3.7 ± 1.9 to 9.0 ± 0.8, with a mean change of 5.2 ± 1.9.

Confidence in decision making improved from 5.2 ± 1.9 to 8.5 ± 1.0 (mean increase: 3.3 ± 1.7); however, confidence in communication demonstrated less growth from 6.3 ± 2.3 to 7.8 ± 1.9

(mean increase: 1.4 ± 2.0). It is likely that the greater amount of growth in communication is attributed to higher pre-simulation scores and a ceiling effect (Table 2).

The descriptive statistics reveal generally symmetrical distributions for all change scores allowing for the use of parametric inferential tests.

Statistical Analyses

Using paired t-tests, all measured variables demonstrated significant improvements post-simulation.

There was a statistically significant improvement in protocol knowledge post-simulation with a mean increase of 5.2 points (95% CI: 4.4 – 6.0; $p < .001$). There was also a statistically significant improvement in trauma management confidence post-simulation with a mean increase of 5.0 points (95% CI: 4.1 – 5.8; $p < .001$) (Table 3).

Additionally, there was a statistically significant improvement in bleeding control post-simulation with a mean increase of 4.5 points (95% CI: 3.6 – 5.3; $p < .001$). Finally, there was a statistically significant improvement in decision-making confidence post-simulation with a mean increase of 3.3 points (95% CI: 2.6 – 4.0; $p < .001$). Communication also demonstrated statistically significant improvements post-simulation with a mean increase of 1.4 points (95% CI: .6 – 2.3; $p = .001$) (Table 3).

Since none of the confidence intervals included zero, there were statistically reliable improvements in all domains of knowledge and confidence.

Objective Knowledge Performance

Case 1 Performance

Performance in Case One Demonstrated Improvement Across Multiple Domains.

The greatest improvement occurred in Question Two, where correct answers increased from 48% before the simulation to 100% after the simulation (a 52% absolute increase; $p < .001$).

Additionally, Questions Four and Five each showed statistically significant improvement as well, demonstrating increases in correct answers from 52% to 76% (an increase of 24%; $p = .016$) and from 32% to 60% (an increase of 28%; $p = .039$), respectively.

Each question for which there existed high pre-test correctness rates (Questions One and Three; both with pre-test correct answer percentages >80%), evidenced relatively minor statistically insignificant changes; therefore, those changes appear to be influenced by ceiling effects.

Finally, although Question Six demonstrated some improvement (from a pre-test correct answer percentage of six percent to eight percent; $p = .625$), it failed to show statistically significant improvement (Table 4).

Case 2 Performance

Performance Demonstrated Significant Improvements in Low Baseline Areas.

Case Two similarly demonstrated significant improvement across areas with previously lower base-line knowledge rates.

Specifically, Question Two showed a dramatic increase in correct answers from sixty-four percent pre-simulated to one hundred percent post-simulated (an increase of thirty-six percent; $p = .004$), and Question Three also showed an increase from forty percent pre-simulated to seventy-six percent post-simulated (an increase of thirty-six percent; $p = .022$).

As expected, given their initially higher base-line rates, Questions One and Six each demonstrated very little statistically nonsignificant change.

Notably, Question Four showed no appreciable increase (actually decreasing slightly, from fifty-two percent pre-simulated to forty-four percent post-simulated; $p = .754$), thus failing to show a statistically significant difference (Table 5).

Therefore, collectively these findings clearly indicate that improvements were most pronounced when based upon the areas of lowest base-line knowledge.

Subjective Evaluation of Simulation Model

Subjects evaluated the simulation model subjectively on multiple dimensions.

The average values obtained from subjects' evaluations were as follows:

- Overall realism: 9.4 ± 1.2
- Trauma realism: 9.0 ± 1.6
- Recommendation: 9.6 ± 0.8
- Engagement: 8.8 ± 1.8
- Preference for simulation over lecture: 9.7 ± 0.9

Median subjective evaluations were ten for several subjective evaluation questions; since strong negative skewness existed for those questions, at least half of the subjects evaluated those questions at the maximum rating level.

At least half of the subjects provided a maximum rating for several questions, including both recommendation and preference for simulation versus traditional lectures (Table 6).

Psychological Stress Induction and Bleeding Feature Subjective Evaluations

The simulation successfully produced psychological stress in subjects since subjects reported high levels of increased stress during the simulation (average: 9.1±1.3).

In terms of subjective evaluations of the simulated bleeding feature, subjects rated every aspect of that feature highly as follows:

- Bleeding realism: 9.2 ± 1.4
- Trauma intensity: 9.0 ± 1.5
- Bleeding-related stress: 8.3 ± 1.7

Collectively, these findings provide evidence that the simulation model produced both realistic emotional and contextual aspects of real-world trauma cases (Table 7).

Thus, collectively these findings demonstrate that the simulation model replicated the stress producing features of real-world trauma cases.

Procedural Fidelity: Replantation, Splinting and Cvek Pulpectomy

Subjects rated each procedural fidelity component as follows:

- Replantation: 9.4 ± 1.1
- Avulsed tooth handling: 9.5 ± 1.0
- Splinting: 9.3 ± 1.3

For each procedural fidelity component, the median subjective evaluation score was ten.

Similarly, the Cvek pulpotomy simulation demonstrated high levels of fidelity as determined by subjects' subjective evaluations.

Average ratings for the Cvek pulpotomy simulation were as follows:

- Experience: 9.1 ± 1.3
- Materials realism: 9.0 ± 1.3

- Pulp removal: 9.2 ± 1.3

For each Cvek pulpotomy domain, the median subjective evaluation score was ten (Table 8).

Subjective Evaluations of subjects' Perceived Satisfaction with the Simulation Structure

Subjects expressed high satisfaction with the simulation structure itself.

A total of ninety-two percent of subjects indicated that they felt that the length of the simulation was "just right," and one hundred percent stated that they found the difficulty to be appropriate for them (Table 10).

Moreover, ninety-two percent recommended repeating the simulation at least two times, further emphasizing their perception of value added by repeated exposure to the simulation model.

Evaluation Of Procedural Accuracy

Although procedural performance reflected significant improvements in knowledge and confidence, procedural performance was characterized by relatively poor accuracy.

The mean procedural accuracy score was sixty-seven-point two percent plus/minus eight-point four percent.

Furthermore, the median procedural accuracy score was seventy percent (inter-quartile range [IQR]: sixty percent – seventy percent) and ranged from fifty percent to eighty-five percent.

Thus, while procedural performance displayed symmetry around the mean procedural accuracy score, it suggests ample variability across different levels of performance.

Based on those findings, it appears that while learners developed knowledge and confidence relative to managing traumatic dental injuries, technical performance still lacked completion following one simulation session.

IV. DISCUSSION

This study evaluated a high-fidelity, CBCT-based 3D printed simulation model intended to increase students' knowledge, confidence and preparedness in pediatric dental trauma management. The results showed a statistically significant gain in self-reported knowledge and confidence across all evaluated areas of assessment after completion of the simulation. Additionally, participants provided high ratings to the model's realism, engagement, ability to induce stress, and educational value. More importantly, the procedural accuracy assessment completed during the simulation (prior to receipt of formal instruction or corrective feedback) showed that students exhibited only clinically unacceptable procedural performance. The finding regarding procedural accuracy is essential to the study as it supports the concept that students who are early in their educational or clinical careers often do not possess the skills to successfully complete even simple clinical tasks related to pediatric dental trauma in the absence of additional hands-on training.

Students' improved confidence and knowledge regarding pediatric dental trauma after completing the simulation indicated that high fidelity experiential learning can provide a substantial benefit in preparing students for the management of pediatric dental trauma. Specifically, students demonstrated a substantial increase in their confidence related to trauma management, bleeding control, decision making, and knowledge of protocols. These areas are important as they relate to the rapid synthesis of diagnostic information, the use of guidelines to make informed decisions, and coordination of procedural execution. Traditional didactic methods may facilitate the student's ability to understand cognitively what they need to know; however, simulation facilitates the student's ability to apply their knowledge in a realistic clinical sequence. Instead of asking students to recognize and/or answer questions about trauma management in isolation, this study allowed students to participate in a clinical situation involving an avulsed permanent incisor, splint placement and treatment of a complicated crown fracture requiring Cvek pulpotomy. This active application likely enhanced the large observed increases in trauma-related confidence and knowledge.

Moreover, students demonstrated the largest improvement in protocol knowledge. Management of pediatric dental trauma relies upon correct interpretation and application of evidence-based guidelines. These guidelines include proper management of avulsed permanent teeth, identification of prognosis related factors (i.e., dry time out of alveolus and storage medium), selection of flexible splints, consideration of antibiotics, establishment of follow-up times and strategies for preserving pulp vitality. Many of these topics are presented in a didactic manner; however, many students will not solidify their understanding until they are asked to apply them in a realistic clinical setting. Thus, the simulation appears to serve as a bridge between memorization of guidelines and practical application of those guidelines.

The baseline procedural accuracy findings further illustrate the necessity of providing this type of training. Although students achieved an average procedural accuracy score of approximately 65% before receiving formal instruction or corrective feedback; this indicates that many students were unable to satisfactorily execute the entire trauma care sequence.

It is imperative to note that this is not indicative of a failure of the simulation itself. Rather, it is one of the most significant findings within this study. The procedural accuracy score illustrates that complex trauma care is much more than being familiar with theoretical concepts.

Students must be able to sequence treatment steps appropriately, control bleeding, handle an avulsed tooth appropriately, remove inflamed pulp tissue correctly, adapt a splint and manage the case in an organized manner. The moderate baseline performance clearly indicates that dental students may have partial knowledge of the theoretical concepts involved in managing traumatic dental injury, but they may not yet have the applied clinical skills needed to perform these procedures independently.

These findings are aligned with the broader educational challenge that traumatic dental injuries are high stakes, low frequency clinical events. Students may graduate with limited direct experience in treating traumatic dental injuries (especially those requiring immediate attention). Consequently, their first meaningful experience managing an avulsion or complicated crown fracture may occur when working independently (where delay or error may lead to serious consequences). The objective data collected via the procedural accuracy portion of this study thus provide empirical evidence that there exists a clinically relevant knowledge-skill gap. Not only did students report feeling unprepared for managing pediatric dental emergencies; but their actual performance supported this claim.

There is considerable difference between knowledge, confidence, and procedural competence. After participating in the simulation, students reported significantly higher levels of confidence and perceived preparedness to manage pediatric dental emergencies. Confidence has been shown to positively influence a provider's willingness to treat an emergency case. Confidence also decreases hesitancy and may enhance communication with parents/caregivers. However, confidence alone does not equate to competence. The data collected using the procedural accuracy score show that prior to structured reinforcement, learners exhibited numerous shortcomings in technical and procedural skills required for independent management.

This highlights the importance of combining subjective outcomes (e.g., confidence) with objective performance measures (e.g., procedural accuracy).

Within this study, the simulation model fulfilled two complementary roles. First, it functioned as an instructional tool by enhancing students' knowledge and confidence following completion of the simulation. Second, it functioned as an assessment tool by demonstrating existing deficiencies in learners' clinical performance prior to receiving formal instruction. One of the greatest benefits associated with designing simulations is that they fulfill both instructional and assessment functions simultaneously. If a simulation is well-constructed; it teaches as it evaluates. In pediatric dental trauma; where errors in early management may ultimately affect long term prognosis; evaluating these deficiencies before students begin interacting with actual patients is particularly beneficial.

Additionally, the high ratings given by students regarding realism and educational value support the utility of this type of model. These results support strong face validity and learner acceptability. The degree of realism incorporated into a simulation model is not just a superficial characteristic; it is an integral part of its instructional purpose. Pediatric dental trauma presents unique visual, emotional, and procedural challenges. Therefore, a rigid typodont lacking any form of bleeding or soft-tissue response cannot adequately simulate the cognitive demands inherent in managing a true emergency. By utilizing CBCT derived anatomy, soft tissue analogs; removable avulsed tooth; complicated crown fracture; splinting; and simulated bleeding; this model attempted to provide a more immersive and clinically relevant experience.

The simulated bleeding was especially noteworthy since participants rated bleeding realism and trauma intensity very highly and experienced elevated levels of bleeding-related stress. Within the context of trauma education, stress is not always detrimental. True pediatric dental trauma cases are stressful due to factors such as pain, bleeding, fearful, uncooperative children, anxious parents/caregivers, time-sensitive decision making, and technically challenging procedures. Thus, if a simulation removes stress from the educational experience, it may provide an easier experience for learners but less representative of real-world practice. The ultimate goal is not to overwhelm students with too much stress but rather provide them with a controlled amount of difficulty that mimics real-world practice as closely as possible. Based on participant responses, the bleeding features appear to have enhanced realism while still being educationally acceptable.

Participant ratings also provide further support for the model's usefulness in educating technically competent skills. Ratings concerning replantation, handling an avulsed tooth, splinting, Cvek pulpotomy, etc., were high. It is important to acknowledge that these skills are difficult to educate using observation alone. Cvek pulpotomy specifically requires an understanding of indications, hemostatic control, controlled removal of inflamed pulp tissue, placement of materials, and restoration of fractured tooth. Preservation of pulp vitality is biologically important for immature permanent teeth as continued root development and apexogenesis depend on maintaining a viable pulp. Simulation provides a means for practicing these steps in a standardized environment prior to interaction with real pediatric patients suffering from traumatic dental injuries.

The study has significant implications for dental education. First, the study supports inclusion of high-fidelity trauma simulation into dental curriculums as a means of increasing trauma knowledge and confidence. Second, it demonstrated that simulation could identify baseline shortages in procedural performance that may go unnoticed by examination alone. Finally, it suggests that learners require repeated exposures to practice, receive feedback, and to gain confidence and competency as they refine their clinical technique. Therefore, pediatric dental trauma training should be viewed as a longitudinal process rather than a singular educational event.

Longitudinal curricula could include sequential trauma simulation training at various points throughout learners' career trajectory. Early sessions could concentrate on didactic teaching of diagnosis, prognosis, and decision-making based on evidence-based guidelines. Subsequent sessions could focus on execution of procedures, splint adaption, pulp therapies, communication with parents/caregivers, and managing cases under time constraints. Repeated exposure would enable learners to transition from cognitive understanding towards procedural proficiency. This approach aligns with principles of motor learning where developing technical skills occurs through repetition, feedback, and correction over time.

Our study has several limitations. First, this study utilized a single group pretest-posttest design without a comparison or control group. Therefore, while significant gains were seen post-simulation, no conclusions can be made definitively attributing all improvements directly to the intervention itself. Familiarity with test content may contribute to some gain. Similarly, short-term recall may have influenced improvement due to familiarity with assessment format. Second, while participants were recruited from a single institution, the University of Washington School of Dentistry, and the small sample size also limits generalizability. Third, outcomes were measured immediately post-simulation; therefore, long-term retention of knowledge, confidence, and procedural skills could not be assessed. Fourth, although students rated the model highly for realism, simulation cannot replicate completely the behavioral complexity of live pediatric patients, caregiver interactions, pain management, or unpredictability of clinical trauma cases.

Future studies should build on these findings by using larger sample sizes and control groups, and multi-site study designs. Randomized studies comparing high-fidelity simulators with and without a simulated bleeding feature would help clarify whether this component provides additional value in preparing learners to manage pediatric dental trauma. Further longitudinal evaluation would allow assessment of the long-term retention of knowledge, confidence, and procedure skill. Future research should investigate whether repeated simulation enhances learners' procedural accuracies and whether learning gains observed in simulation translate to "real" clinical settings.

Emerging technologies will potentially offer new opportunities for advancing this type of educational endeavor. The surge of Artificial Intelligence (AI) technology could provide learners with real-time feedback regarding procedural steps, identify errors in sequencing and score technical performances more objectively. Augmented/Virtual Reality (AR/VR) technology could be overlaid onto physical models, allowing learners to interactively practice decision-making processes, dynamically simulate bleeding scenarios, and engage in caregiver communication modules.

V. CONCLUSION

This research demonstrates that using a CBCT-based 3D-printed pediatric dental trauma simulation model is an effective, valid, and well-accepted educational method for enhancing knowledge, increasing confidence and preparation, as well as being acceptable for use by dental students as an educational tool for managing dental trauma. By providing a hands-on, realistic training environment, this simulation model allowed dental students to simulate complex pediatric dental trauma procedures such as avulsion management, splinting and Cvek pulpotomy in a safe and controlled environment. Dental students at baseline demonstrated the need for additional applied clinical experience and training with regard to accurately completing procedural components associated with pediatric dental trauma management. Overall, the results of this study support the inclusion of repeated, high fidelity simulation models within dental curricula to assist in bridging the gap between theoretical knowledge of pediatric dental trauma and the ability to perform clinically. Future studies will be needed to evaluate the effects of repeated simulation on long term retention of skills and the potential benefits/risks of repeating multiple simulations.

VI. FIGURES AND TABLES:

Table 1. Participant demographics.

Category	Variable	Value
Demographics	Age (years)	
	Mean ± SD	28.2 ± 4.9
	Median (IQR)	27 (25-29)
	Range	24-40
	Skewness	1.2
	Gender	
	Female	23 (92%)
	Male	2 (8%)
Training Level	Year	
	D3	21 (84%)
	D4	4 (16%)
Clinical Experience	Pediatric Experience	
	No experience	1 (4%)
	Limited	10 (40%)
	Moderate	9 (36%)
	Extensive	5 (20%)
	Trauma Experience	
	No experience	9 (36%)
	Limited	10 (40%)
	Moderate	3 (12%)
	Extensive	3 (12%)

Table 2. Full descriptive summary of pre-simulation, post-simulation, and post-pre change scores across trauma related confidence and knowledge domains

Variable	Pre (N=25)	Post (N=25)	Post-Pre (N=25)
Trauma management			
Mean (SD)	3.6 (2.0)	8.6 (1.0)	5.0 (2.1)
Median (IQR)	3.0 (2.0, 4.0)	9.0 (8.0, 9.0)	5.0 (4.0, 6.0)
Min to Max	1.0, 8.0	7.0, 10.0	0.0, 9.0
Skewness	0.9	0.0	-0.4
Bleeding control			
Mean (SD)	4.1 (2.3)	8.6 (1.0)	4.5 (2.0)
Median (IQR)	3.0 (2.0, 6.0)	9.0 (8.0, 9.0)	6.0 (3.0, 6.0)
Min to Max	1.0, 8.0	7.0, 10.0	0.0, 7.0
Skewness	0.5	-0.3	-0.8
Decision making			
Mean (SD)	5.2 (1.9)	8.5 (1.0)	3.3 (1.7)
Median (IQR)	5.0 (4.0, 7.0)	8.0 (8.0, 9.0)	3.0 (2.0, 4.0)
Min to Max	2.0, 9.0	7.0, 10.0	1.0, 7.0
Skewness	0.3	0.1	0.3
Communication			
Mean (SD)	6.3 (2.3)	7.8 (1.9)	1.4 (2.0)
Median (IQR)	7.0 (4.0, 8.0)	8.0 (7.0, 9.0)	1.0 (0.0, 2.0)
Min to Max	2.0, 10.0	2.0, 10.0	-2.0, 7.0
Skewness	-0.2	-1.2	0.9
Protocol knowledge			
Mean (SD)	3.7 (1.9)	9.0 (0.8)	5.2 (1.9)
Median (IQR)	4.0 (2.0, 5.0)	9.0 (8.0, 10.0)	5.0 (4.0, 7.0)
Min to Max	1.0, 7.0	8.0, 10.0	2.0, 8.0
Skewness	0.3	0.1	-0.2

Table 3. Test and Confidence Interval for Change. Answering if participants improved in this domain after the simulation

Variable	Pre (N=25)	Post (N=25)	Post-Pre	95% CI	P-value
Trauma management					
Mean (SD)	3.6 (2.0)	8.6 (1.0)	5.0 (2.1)	4.1, 5.8	<.001
Min to Max	1.0, 8.0	7.0, 10.0	0.0, 9.0		
Bleeding control					
Mean (SD)	4.1 (2.3)	8.6 (1.0)	4.5 (2.0)	3.6, 5.3	<.001
Min to Max	1.0, 8.0	7.0, 10.0	0.0, 7.0		
Decision making					
Mean (SD)	5.2 (1.9)	8.5 (1.0)	3.3 (1.7)	2.6, 4.0	<.001
Min to Max	2.0, 9.0	7.0, 10.0	1.0, 7.0		
Communication					
Mean (SD)	6.3 (2.3)	7.8 (1.9)	1.4 (2.0)	0.6, 2.3	.001
Min to Max	2.0, 10.0	2.0, 10.0	-2.0, 7.0		
Protocol knowledge					
Mean (SD)	3.7 (1.9)	9.0 (0.8)	5.2 (1.9)	4.4, 6.0	<.001
Min to Max	1.0, 7.0	8.0, 10.0	2.0, 8.0		

Table 4. Case One Participant Performance

Variable	Pre (N = 25[1])	Post (N = 25[1])	Pre-Post (95% CI)	P-value
Case 1 Qx 1	21 (84.0%)	25 (100.0%)	16% (0, 37)	.125
Case 1 Qx 2	12 (48.0%)	25 (100.0%)	52% (29, 72)	<.001
Case 1 Qx 3	21 (84.0%)	25 (100.0%)	16% (0, 37)	.125
Case 1 Qx 4	17 (68.0%)	24 (96.0%)	24% (2, 46)	.016
Case 1 Qx 5	9 (36.0%)	16 (64.0%)	28% (4, 50)	.039
Case 1 Qx 6	22 (88.0%)	24 (96.0%)	8% (-11, 27)	.625

Table 5. Case Two Participant Performance

Variable	Pre (N = 25[1])	Post (N = 25[1])	Pre-Post (95% CI)	P-value
Case 2 Qx 1	21 (84.0%)	25 (100.0%)	16% (0, 37)	.125
Case 2 Qx 2	16 (64.0%)	25 (100.0%)	36% (15, 57)	.004
Case 2 Qx 3	10 (40.0%)	19 (76.0%)	36% (8, 59)	.022
Case 2 Qx 4	13 (52.0%)	11 (44.0%)	-8% (-33, 18)	.754

Table 6. Overall Model Assessment

Variable	N = 25
Trauma	
Mean (SD)	9.0 (1.6)
Median (IQR)	10.0 (8.0, 10.0)
Min to Max	3.0, 10.0
Skewness	-2.3
Recommend	
Mean (SD)	9.6 (0.8)
Median (IQR)	10.0 (10.0, 10.0)
Min to Max	8.0, 10.0
Skewness	-1.6
Realistic	
Mean (SD)	9.4 (1.2)
Median (IQR)	10.0 (9.0, 10.0)
Min to Max	5.0, 10.0
Skewness	-2.1
Engagement	
Mean (SD)	8.8 (1.8)
Median (IQR)	10.0 (8.0, 10.0)
Min to Max	5.0, 10.0
Skewness	-1.1
Bleeding Stress	
Mean (SD)	6.5 (3.1)
Median (IQR)	7.0 (5.0, 9.0)
Min to Max	1.0, 10.0
Skewness	-0.4
Increased Stress	
Mean (SD)	9.1 (1.3)
Median (IQR)	10.0 (8.0, 10.0)
Min to Max	5.0, 10.0
Skewness	-1.4
Lecture vs Simulation	
Mean (SD)	9.7 (0.9)
Median (IQR)	10.0 (10.0, 10.0)
Min to Max	6.0, 10.0
Skewness	-2.8

Table 7. Simulated Bleeding Feature Assessment

Variable	N = 25
Bleeding Realism	
Mean (SD)	9.2 (1.4)
Median (IQR)	10.0 (9.0, 10.0)
Min to Max	5.0, 10.0
Skewness	-1.7
Bleeding Trauma	
Mean (SD)	9.0 (1.5)
Median (IQR)	10.0 (8.0, 10.0)
Min to Max	5.0, 10.0
Skewness	-1.3
Bleeding Stress	
Mean (SD)	8.3 (1.7)
Median (IQR)	8.0 (7.0, 10.0)
Min to Max	4.0, 10.0
Skewness	-0.8

Table 8. Replantation and Splinting-Specific Assessment

Variable	N = 25
Replanting	
Mean (SD)	9.4 (1.1)
Median (IQR)	10.0 (9.0, 10.0)
Min to Max	6.0, 10.0
Skewness	-1.8
Avulsed Tooth	
Mean (SD)	9.5 (1.0)
Median (IQR)	10.0 (10.0, 10.0)
Min to Max	6.0, 10.0
Skewness	-2.2
Splint	
Mean (SD)	9.3 (1.3)
Median (IQR)	10.0 (9.0, 10.0)
Min to Max	4.0, 10.0
Skewness	-2.6

Table 9. Cvek Pulpotomy-Specific Assessment

Variable	N = 25
Cvek	
Mean (SD)	9.1 (1.3)
Median (IQR)	10.0 (8.0, 10.0)
Min to Max	6.0, 10.0
Skewness	-1.0
Pulpotomy Materials	
Mean (SD)	9.0 (1.3)
Median (IQR)	10.0 (8.0, 10.0)
Min to Max	6.0, 10.0
Skewness	-0.7
Pulp Removal	
Mean (SD)	9.2 (1.3)
Median (IQR)	10.0 (8.0, 10.0)
Min to Max	6.0, 10.0
Skewness	-1.1

Table 10. Participant Feedback

Variable	N = 25[1]
Duration	
Too short	2 (8.0%)
Just right	23 (92.0%)
Too long	0 (0.0%)
Difficulty	
Too easy	0 (0.0%)
Appropriate	25 (100.0%)
Too difficult	0 (0.0%)
No. Repetitions	
Once	2 (8.0%)
Twice	23 (92.0%)
As many as possible	0 (0.0%)

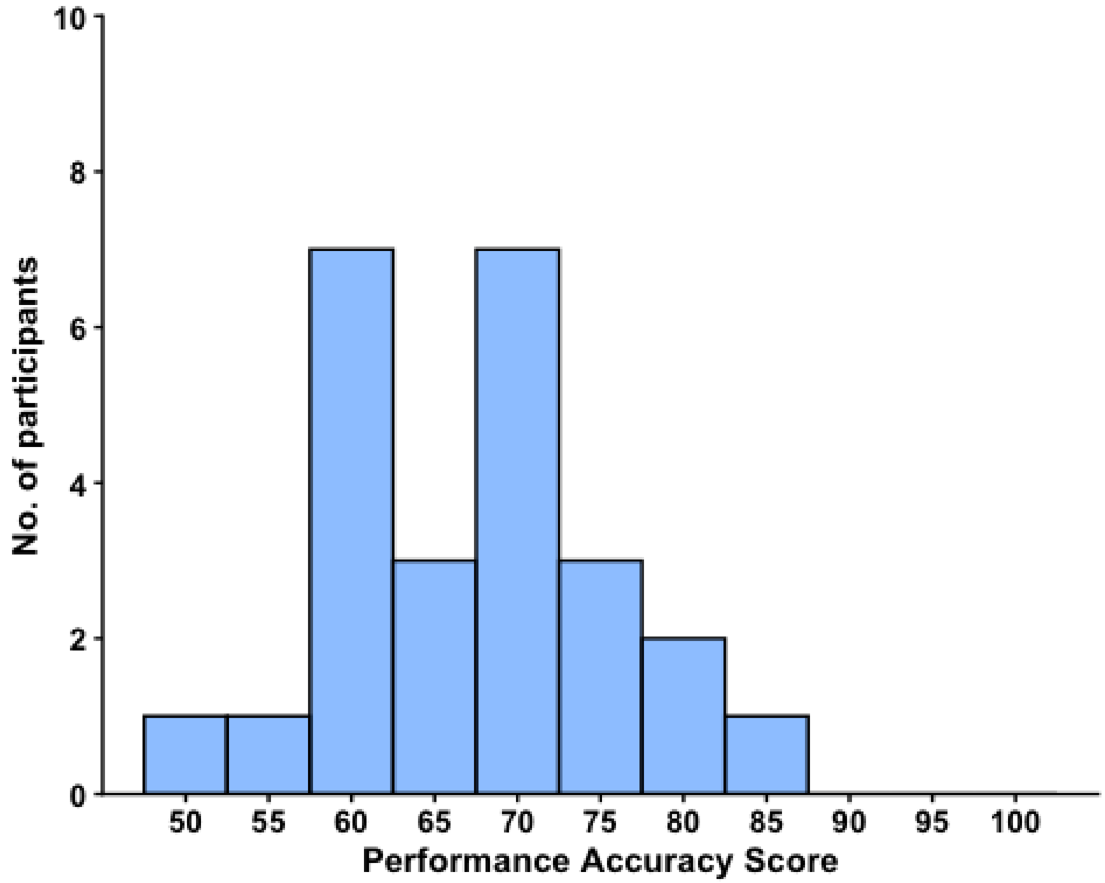

Figure 1. Histogram of Participant Procedure Accuracy

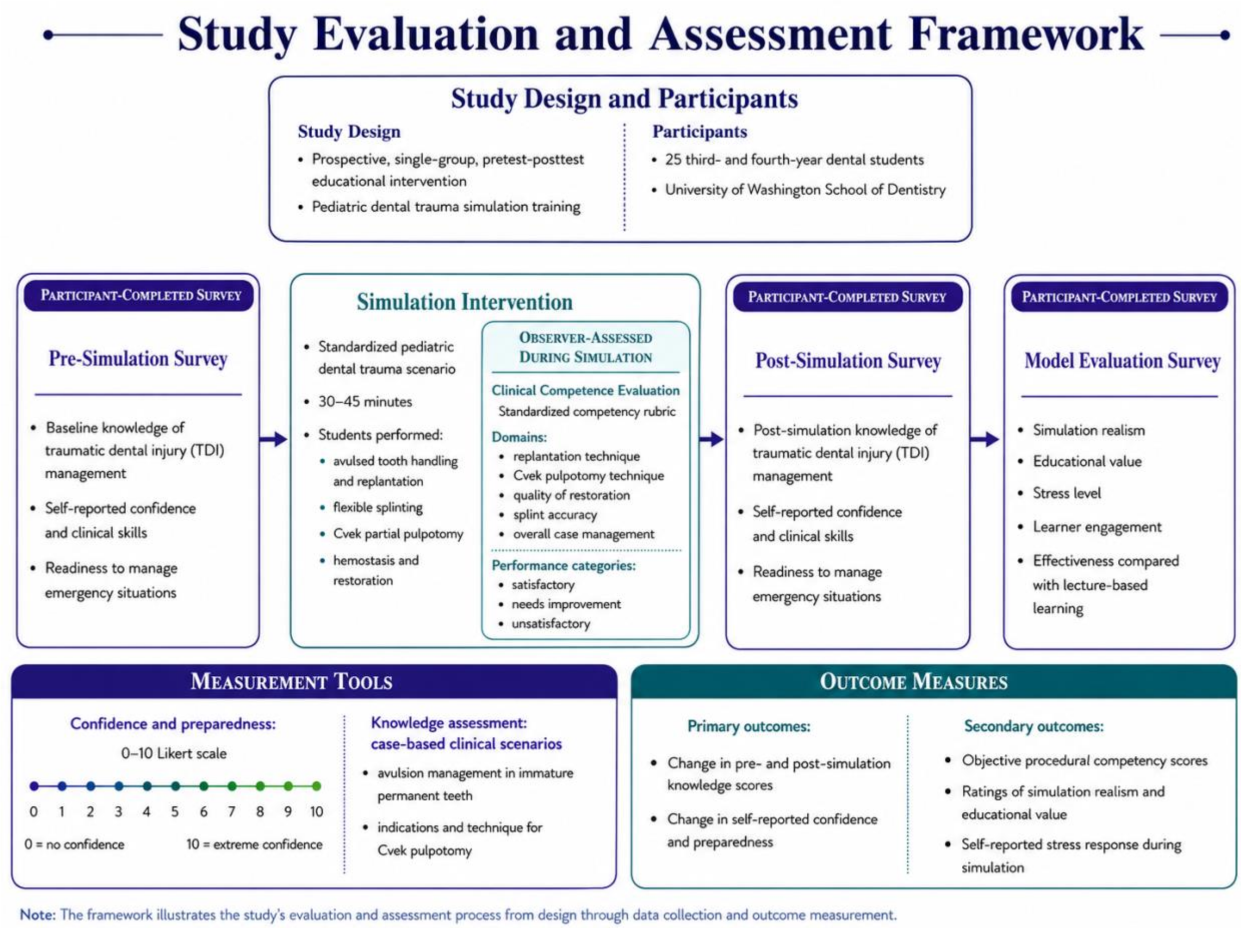

Figure 2. Study evaluation and assessment framework illustrating the single-group pretest–posttest design, simulation intervention, measurement tools, and primary and secondary outcome measures used to evaluate pediatric dental trauma training.

VII. APPENDIX:

<u>Surveys</u>

Pre- and Post-Simulation Surveys

Pediatric Dental Trauma Simulation Training

Pre-Simulation Survey

This survey is designed to assess baseline knowledge, confidence, and preparedness before participating in the trauma simulation.

Section 1: Demographics & Background

1. What is your current role?

☐ 3rd-year dental student

☐ 4th-year dental student

2. What is your age

☐ ___

3. What is your gender?

☐ Male

☐ Female

☐ Other ____

4. Please indicate your level of experience treating pediatric dental patients?

☐ No Experience

☐ Limited (< 10 patients)

☐ Moderate (11-30 patients)

☐ Extensive (> 30 patients)

5. Previous experience with dental trauma cases (including observing and assisting):

☐ No Experience

☐ Limited (1-2 cases)

☐ Moderate (3-5 cases)

☐ Extensive (> 10 cases)

Section 2: Pre-Training Assessment

(0 = Not confident at all, 10 = Extremely confident):

1. Confidence in managing pediatric dental trauma:
☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

2. Confidence in controlling bleeding during pediatric dental procedures:
☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

3. Confidence in making clinical decisions under pressure:
☐0☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

4. Confidence in communicating with pediatric patients and parents during:

☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

5. Knowledge of pediatric dental trauma management protocols:

☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

Section 3: Knowledge Assessment

Case 1: Tooth #8 – Avulsion

An 8-year-old boy, who weighs 56kg, presents 40 minutes after falling off a bike. Tooth #8 is avulsed and was stored in milk by the parent. The child is healthy, and the tooth has an immature apex.

1. What is the recommended management for this avulsed permanent incisor with an open apex?
☐ Replant immediately, flexible splint 2-4 weeks, no RCT unless necrotic
☐ Replant, perform root canal immediately
☐ Do not replant - immature apex has poor prognosis
☐ Prior to replanting, soak in a fluoride and antibiotic rinse and then replant

2. What is the prognosis of this avulsed tooth?
☐ Questionable
☐ Favorable
☐ Poor
☐ Non-viable

3. What type of splint is recommended for replanted teeth?
☐ Rigid splint for 6 weeks
☐ Flexible splint for 2-4 weeks
☐ Steel wire splint for 1 week
☐ No splint needed

4. Should antibiotics be prescribed for this patient after replantation of an avulsed permanent tooth?
☐ Yes
☐ No
☐ Not sure

5. If yes, which of the follow antibiotic prescriptions is correct for this patient (8 year old male, 56kg)?
☐ Amoxicillin 20 mg/kg/day once daily
☐ Amoxicillin 50 mg/kg/day in divided doses every 8 hours
☐ Clindamycin 20 mg/kg/day every four hours
☐ Ciprofloxacin 10 mg/kg every 3 hours

6. What is the correct follow-up schedule for this patient?
☐ No follow-up required
☐ Every 6 months
☐ 2 weeks, 4 weeks, 3 months, 6 months, one year, and yearly thereafter for at least five years
☐ Annually

Case 2: Tooth #9 – Complicated Crown Fracture

Tooth #9 presents with a 1mm pulp exposure from a traumatic fracture. The child is 8 years old with an open apex. The injury occurred within the last 2 hours. Radiograph confirms no root fracture or displacement, and no cortical plate fracture.

4. What is the ideal management for this complicated crown fracture in a permanent incisor with an open apex?
☐ Cvek pulpotomy
☐ Regenerative Endodontics
☐ Root Canal Therapy
☐ Extraction

5. What material is recommended to place over the pulp in a Cvek pulpotomy?
☐ Calcium hydroxide

☐ White MTA
☐ Glass ionomer
☐ Eugenol

6. How much coronal pulp is typically removed in a Cvek pulpotomy?
☐ 1 mm
☐ 2 mm
☐ 3–4 mm
☐ Entire pulp chamber

7. What is the ideal time frame to treat a traumatic pulp exposure to preserve pulp vitality?
☐ Within 6 hours
☐ Within 24 hours
☐ Within 48 hours
☐ Time frame is not important

Post-Simulation Survey

This survey is designed to evaluate changes in knowledge, confidence, and preparedness following the simulation.

Section 1: Post-Training Assessment

(0 = Not confident at all, 10 = Extremely confident):

1. Confidence in managing pediatric dental trauma:
☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

2. Confidence in controlling bleeding during pediatric dental procedures:
☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

3. Confidence in making clinical decisions under pressure:
☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

4. Confidence in communicating with pediatric patients and parents during:

☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

5. Knowledge of pediatric dental trauma management protocols:

☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

Section 2: Knowledge Retention

Case 1: Tooth #8 – Avulsion An 8-year-old child presents 45 minutes after falling off a bike. Tooth #8 is avulsed and was stored in milk by the parent. The child is healthy, and the tooth has an immature apex.

1. What is the recommended management for this avulsed permanent incisor with an open apex?

☐ Replant immediately, flexible splint 2-4 weeks, no RCT unless necrotic

☐ Replant, perform root canal immediately

☐ Do not replant -- immature apex has poor prognosis

☐ Store in fluoride gel and replant in 24 hrs

2. What is the prognosis of this avulsed tooth?

☐ Questionable

☐ Favorable

☐ Poor

☐ Non-viable

3. What type of splint is recommended for replanted teeth?

☐ Rigid splint for 6 weeks

☐ Flexible splint for 2-4 weeks

☐ Orthodontic bracket and steel wire splint for 4 weeks

☐ No splint needed

4. Should antibiotics be prescribed for this patient after replantation of an avulsed permanent tooth?

☐ Yes

☐ No

☐ Not sure

5. If yes, which of the follow antibiotic prescriptions is correct for this patient (8 year old male, 56kg)?

☐ Amoxicillin 20 mg/kg/day once daily

☐ Amoxicillin 50 mg/kg/day in divided doses every 8 hours

☐ Clindamycin 20 mg/kg/day every four hours

☐ Ciprofloxacin 10 mg/kg every 3 hours

6. What is the correct follow-up schedule for this patient?
☐ No follow-up required
☐ Every 6 months
☐ 2 weeks, 4 weeks, 3 months, 6 months, one year, and yearly thereafter for at least five years
☐ Annually

Case 2: Tooth #9 – Complicated Crown Fracture

Tooth #9 presents with a 1mm pulp exposure from a traumatic fracture. The child is 8 years old with an open apex. The injury occurred within the last 2 hours. Radiograph confirms no root fracture or displacement, and no cortical plate fracture.

4. What is the ideal management for this complicated crown fracture in a permanent incisor with an open apex?
☐ Cvek pulpotomy
☐ Regenerative Endodontics
☐ Root Canal Therapy
☐ Extraction

5. What material is recommended to place over the pulp in a Cvek pulpotomy?
☐ Calcium hydroxide
☐ White MTA
☐ Glass ionomer
☐ Eugenol

6. How much coronal pulp is typically removed in a Cvek pulpotomy?
☐ 1 mm
☐ 2 mm
☐ 3–4 mm
☐ Entire pulp chamber

7. What is the ideal time frame to treat a traumatic pulp exposure to preserve pulp vitality?
☐ Within 6 hours
☐ Within 24 hours
☐ Within 48 hours
☐ Time frame is not important

Section 3: Training Model Evaluation

Instructions: Please rate your agreement with the following statements using the scale below (0 = Strongly disagree, 10 = Strongly agree).

Overall Model Assessment

1) The simulation model helped me understand pediatric dental trauma management:
   ☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

2) The simulation model can be recommended for pediatric dental trauma training:
   ☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

3) The simulation model provided a realistic learning experience and has high educational value:
   ☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

4) Level of stress during the simulation (1 = not at all, 10 = extremely)
   ☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

5) Level of engagement during the simulation (1 = not at all, 10 = extremely)
   ☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

6) The simulated bleeding feature increased my stress level (1 = strongly disagree, 10 = strongly agree:
   ☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

7) The increased stress level was beneficial for my learning (1 = strongly disagree, 10 = strongly agree:
   ☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

8) Compared to traditional lecture-based learning, this simulation was more effective for learning and education (1 = strongly disagree, 10 = strongly agree)
   ☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

Simulated Bleeding Feature Assessment

9) The simulated bleeding feature enhanced the realism of the simulation:
   ☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

10) The simulated bleeding feature prepared me better for real trauma situations:
   ☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

11) The simulated bleeding feature increased my stress management skills:
☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

Replantation & Splinting–Specific

12) The simulation helped me understand the step-by-step process of replanting an avulsed permanent tooth:
☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

13) The exercise improved my ability to handle the avulsed tooth appropriately before replantation:
☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

14) I feel more confident in placing and adapting a flexible splint correctly:
☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

Cvek Pulpotomy-Specific

15) The simulation helped me understand the indications for Cvek pulpotomy in complicated crown fractures:
☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

16) The simulation improved my ability to handle and apply pulpotomy materials (e.g., MTA) effectively:
☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

17) Practicing Cvek pulpotomy in a bleeding model improved my skill in partial pulp removal and medicament placement:
☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

Section 4: Training Duration and Difficulty

1) The duration of the training session was:

- [ ] Too short

- [ ] Just right

- [ ] Too long

2) The difficulty level of the simulation was:**

- [ ] Too easy
- [ ] Appropriate
- [ ] Too difficult

3) How many times would you find it helpful to repeat this simulation?**

- [ ] 0 (One time is enough)
- [ ] 1 additional time
- [ ] 2 times
- [ ] As many times as possible

Competency Evaluation Rubric: Pediatric Dental Trauma Simulation

Procedure Component	**Satisfactory (20 points)**	**Needs Improvement (15)**	**Unsatisfactory (10)**
Replantation of Avulsed Tooth	Proper handling, correct socket placement, minimal extraoral time	Minor errors in positioning or handling	Incorrect placement or excessive extraoral time
Cvek Pulpotomy	Clean exposure, proper pulp removal, effective hemostasis	Minor bleeding control issues, slight material placement errors	Major pulp exposure errors, failure to control bleeding
Restoration of Coronal Fracture	Restoration mimics anatomy and occlusion	Minor occlusal/contact adjustments needed	Poorly contoured, overextended, or open margins
Splinting	Correct flexible splint, proper adaptation, good stability	Slight errors in retention or positioning	Rigid, poorly adapted, or ineffective splint
Overall Case Management	Accurate diagnosis, efficient workflow, clear communication	Some hesitation or missteps in execution	Major procedural delays, misdiagnosis

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