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Exploring Dynamic Navigation For Palatally Impacted Canine Uncovery Surgery.

Daniel Joseph Hall

Exploring Dynamic Navigation For Palatally Impacted Canine Uncovery Surgery.

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

By

Daniel Hall, DMD

Georgia Southern University, 2015

University of Kentucky College of Dentistry, 2019

Thesis advisor: Dr. Janina Deeb, DDS, MS

Associate Professor Department of Periodontics

Virginia Commonwealth University

Richmond, Virginia

May, 2022

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Abstract

EXPLORING DYNAMIC NAVIGATION FOR PALATALLY IMPACTED CANINE UNCOVERY SURGERY

By: Daniel Hall, D.M.D.

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Thesis Advisor: Janina Golob Deeb, DMD, MS

VCU Graduate Department of Periodontics

Purpose: The objective of this study was to compare the exposure/uncovery of palatally impacted canines via the use of dynamic navigation guidance to the traditional freehand approach. Outcomes evaluated include the time to plan and perform exposure, area/size of initial access to locate the impacted tooth and the final size of the osteotomy to completely uncover the impacted tooth.

Methods: In order to simulate various frequently encountered clinical scenarios, three different model types were used. Six plastic models of each model type were fabricated from epoxy resin. Each model contained 2 bilaterally, palatally impacted canines, that were randomly embedded in the models, in the canine region. Impacted canines were exposed by either a traditional approach, or guided by dynamic navigation randomly assigned to the right and left side of the same model.

Time to plan/prepare, drill, and sizes of the initial and final osteotomy to expose the impacted teeth were measured and compared for the two methods.

Results: Bilaterally, palatally impacted canines were exposed either with the freehand or with guided navigation approach in 18 models, a total of 36 sites evenly distributed. The time to prepare for the procedure was significantly longer for the guided navigation experiments ($p<.0001$). Preparation time was on average 10:07 for guided navigation and 3:19 for freehand. The time to locate the tooth was significantly different on the left side of the models with guided taking approximately 2 minutes longer than freehand (122.78s; $p=.0423$) but did not differ significantly on the right (16.78s longer for freehand; $p=.9809$). The time to finish the procedure did not differ significantly based on the method ($p=0.8342$) or the side of the model ($p=.3441$). The total time was significantly longer for the guided navigation (7:48; $p<.0001$). Based on a volumetric assessment, the size of the initial osteotomy was significantly smaller for guided navigation on the right side of the models by an average of 7.13mm^3 (adjusted $p=.0097$). The difference on the left side of the models was not significant (1.86mm^3, $p=.9933$). The total volume removed did not differ significantly between the two methods (78.9 vs 77.4 mm^3; $p=.7793$) or on the side of the model (79.1 vs 77.2 mm^3, $p=.7175$).

Conclusion: Within the limitations of this study, dynamic navigation methods require more time to prepare prior to initiation of surgery, as well as to locate the impacted canine on the left side of the palate, for a right handed operator. Initial access volume was significantly smaller with dynamic navigation on the right side, but the benefit was not seen on the opposite side. No

significant differences were seen in the time to finalize the osteotomy or the final size. Dynamic navigation could add significant value to a surgeon in certain clinical presentations, such as proximity to vital structures and adjacent roots, despite the increased time for preparation.

Introduction

Impacted canines

Permanent maxillary canines begin to calcify at 12 months of age between the roots of the first deciduous molar, resulting in the longest development period and longest eruptive pathway to travel before arriving into dental occlusion.[1] Coulter quantified Broadbent's observations, finding that canines travel an average distance of 11.48mm horizontally, 2.67mm laterally, 18.56mm vertically, for a total of 22mm across all three planes.[2] Not only can a canine's trajectory be influenced by other teeth, but it can influence the alignment of other teeth as well. For example, between 8-9 years old, the canine crowns impinge on developing lateral incisor roots, driving them medially and causing the crowns to flare laterally. This is referred to in the orthodontic and pediatric literature as the 'Ugly Duckling' stage or 'Broadbent's Phenomenon.' The ensuing pathway to eruption is normally guided by the lateral aspect of the lateral incisor into the arch with proper alignment of the incisors, but deviations from this pathway can result in displacement or impaction. Around the age of 11 to 12 years old, adult canines begin to erupt into the dental arch.[3] Failure to do so results in unfavorable clinical situations including tooth displacement or impaction. Displaced teeth refer to those which have an abnormal position, whereas impacted teeth are those which cannot naturally erupt, usually because they are impeded by other teeth or bone. Four distinct etiologic factors have been identified including local hard tissue obstruction, local pathology, departure or disturbance from the normal development of the surrounding teeth, and hereditary or genetic factors.[4] Second, to mandibular third molars, maxillary canines are the most commonly displaced or impacted permanent teeth.[5] Labial impactions are typically due to insufficient arch length, while 85% of palatally impacted canines had sufficient space to erupt into the dental arch,[6] yet palatal impactions account for two-thirds of maxillary canine impactions.[7,8] Given the many opportunities for a canine to become impacted it's not surprising the reported prevalence of impacted canines in the literature is estimated between 0.9-3% of patients within different populations, 8% of which occur bilaterally.[9–13]

Identification

Canine impactions often go unidentified beyond the normally expected eruption timeline, as they typically erupt later in the sequence of maxillary teeth, in addition to the close resemblance of the deciduous and permanent canines. Thus, early identification and prediction of clinical situations in which canine impactions are anticipated are critical. In the mixed dentition evaluated on panoramic radiographs, 78% of impacted canines were identified when their cusp tips overlapped or were located mesial to the long axis of the erupted lateral incisor root.[14] There are three methods to localize an impacted maxillary canine: inspection, palpation and radiography.[15] During a clinical exam the lack of a "canine bulge", shouldn't be interpreted as the presence of an impacted canine. In children ages 10-12, only 29% had nonpalpable canines, 5% at 11 years old, and 3% thereafter. Thus, the clinical exam should be supplemented with a radiographic evaluation.[16]

Historically, a vertical or horizontal shift of the x-ray beam was used to determine the position of an impacted tooth.[17,18] The buccal shift rule states that when comparing two periapical radiographs, taken at slightly different horizontal positions, the more buccal object will move in the opposite direction of the x-ray beam.[17] The S.L.O.B. mnemonic(same, lingual, opposite, buccal) can be used to remember the rule. The buccal object rule was later improved upon by using panoramic and occlusal radiographs, as it provides information about all teeth in both arches, as well as requiring one additional exposure relative to a typical radiographic exam.[19,20]

Currently, Cone-Beam Computer Tomography system(CBCT) is the gold standard for locating, evaluating, and planning treatment of impacted teeth.[21] These three-dimensional scans also allow the operator to reliably assess impacted teeth and determine the surgical approach to best avoid important anatomical structures or navigate into tight spaces, such as between nearby roots.[22] CBCT imaging is precise in determining the labio-lingual relationship, as well as, a more exact angulation of the impacted canine, which can greatly influence the approach selected by the referring orthodontist and surgeon. This technology has influenced not only the types of procedures performed, but also how they are performed, their safety, efficacy, and efficiency.[23] CBCTs may also be utilized to determine the vector of force that is best to move the tooth into the arch to reduce the chance of adjacent root resorption.[24]

Treatment Options

Ericson and Kurol studied the eruption patterns of ectopically displaced permanent canines in relation to the root of the lateral incisor.[24] In 78% of the consecutive cases followed in their study, they found that extraction of the deciduous canine would allow self-correction of the ectopic permanent canine, if the crown tip was not past the mesial surface of the lateral incisor root. However once an impacted canine is identified, management often involves surgical exposure, followed by 18-29 months of orthodontic treatment.[25,26] Surgical treatment can be approached by essentially one of three options.[27–30] First, open-flap exposure and spontaneous eruption. Second, open-flap exposure and immediate or delayed bonding of an auxiliary. Third, closed-flap exposure and bonding of an attachment during the surgery. The literature supports positive outcomes with each of these approaches and does not favor one over the other in terms of periodontal outcomes.[31–34] Kokich outlined four factors that should be considered when choosing the technique to be used, including labio-lingual position, vertical position relative to the mucogingival junction, mesiodistal position, and the type and quantity of the surrounding tissues.[30]

Treatment Planning

The introduction of technological advances such as cone-beam computed tomography(CBCT) devices and implants are continuing to make their way into dental care. These technologies influence not just the types of procedures performed, but also how they are performed, their safety, efficacy, and efficiency. CBCT scans are the imaging of choice in complex orthodontic cases with impacted canines.[35] In recent years, a computer-aided system referred to as guided navigation has been explored, most notably in implant dentistry. In this application, the technology enables the operator to pre-plan an osteotomy of desired angulation, dimensions and position with a computer system on a preoperative CBCT. This virtual plan is then turned into a guided access which with the help of computer software, fiducial landmarks and a stereolithic camera guides the drill directly to the desired location.[36] Dynamic navigation systems allow the surgeon to fully visualize the osteotomy and implant site during preparation, while the monitor provides real-time video feedback which is used to guide the osteotomy and minimize positional deviations. Indications for dynamic navigation have been studied and reviewed. Some indications for dynamically guided surgery include flapless surgery, patients with limited mouth opening or difficult access, when direct visualization is difficult, tight anatomical spaces, or proximity to vital structures. There are drawbacks to this approach such as additional treatment time, cost of equipment, learning curve to be able to use the system, and potential difficulty to use the system in posterior regions of the mouth due to access. On the other hand, advantages include real-time visualization, accuracy, minimal collateral morbidity, and predetermined access.

For these reasons, applying this technology to surgical canine exposure could also translate several of these benefits to an essentially unchanged surgical approach, particularly in areas with close proximity to anatomical structures or dental crowding. The purpose of this study is to investigate the application of dynamic navigation guidance for use in surgical exposure of palatally impacted canines and compare it to the traditional freehand approach.

Methods

Two exposure methods were planned and compared for canine exposure: freehand approach and guided dynamic navigation access to the impacted teeth on the right and left sides of the same model. A randomization schedule was used to determine the order in which each model type was used, the order of right or left side, and the method of access to be used on each side. Each access was performed to be ideal, minimally invasive with the minimum material removed for the operator to locate and orient himself to the tooth in order to eventually completely uncover the impacted canine. Each model was considered as two trials, right and left. The time to plan and prepare for both procedures and time to access and expose the canine was measured and compared.

Model Fabrication

In order to simulate a variety of frequently encountered clinical scenarios, three factory-fabricated (3D printed) plastic model types were chosen, based on areas of missing dentition and edentulous space configurations. Polyvinyl siloxane(PVS) molds were made of the three model types in order to reproduce them(Figure 1). Six models of each model type were fabricated using epoxy(Figure 2) containing lead powder(Figure 3) for radiopacity. Each model was fabricated to contain two ‘impacted’ canines, that were individually wrapped in molding clay(Figure 4), then randomly embedded within the epoxy, in roughly the canine location on the right and the left side of the maxillary palate(Figure 5). A CBCT was taken for each model (CBCT1).

Dynamic Navigation

The same timing protocol for the preparation process was completed for dynamic navigation, but requires several additional steps. All trials were carried out with the Navident dynamic navigation system set up and used in the same fashion. A JawTag was attached to the typodont and a handpiece was attached to a tracer tag with recognition patterns(Figure 6). In this study, the patient JawTag and handpiece tracer tags were not moved or removed and replaced between trials. The Navident working field was prepared by placing the Navident device in front of the operator so that the camera is located above the operating field and the operator can easily see the computer screen during the procedure displaying the CBCT plan and activity on the virtual display. Here the Navident system provides real-time feedback on the deviations of the drill or instrument tip from the ideal planned position. Recognition tracer tags must be visible to the camera at all times for this system (through a stereoscopic camera) to accurately track movement, relate it to the plan on CBCT and provide the operator with feedback. The operator utilizes the Navident system computer screen, which provides location information and allows manipulation of the CBCT(Figure 7). With tracing tags in place, the Navident software is used to select a CBCT file, which has been preloaded onto a portable storage or USB device, then the jaw arch is traced in the correct axial plane similar to the freehand protocol. Next the software is used to orient the model or patient spatially in relation to the tracing tags and CBCT. The process entails selecting 3-6 landmarks and 'painting' the model with the tip of a registration tracing tool until the system recognizes the tip in the same anatomical area(Figure 8). Additionally, the drill's bur length and axis of rotation must be calibrated. The calibration of the tracer and drill's bur is performed using a 'calibration block' which has designated dimples to accept the instrument tips, as well as drill shank replicas for the drill to rotate on as part of the axis calibration(Figure 8, Figure 9). Once in the field of view the system prompts the operator to twist or hold steady. Finally the surgical access to the desired location must be planned(Figure 10). The location of the access was planned as if an osteotomy was being prepared. The osteotomies planned were 3mm in diameter to a depth just beyond the hard tissue stopping within the follicle. Prior to initiation of the uncovery, the software recommends a final verification of calibration by touching the tip of the bur to the model and verifying its location on the appropriate landmark. If at this time, the positioning in the software and clinically do not coincide, then the operator must repeat the calibration and planning process again. This is one reason that the JawTag on the patient was attached to the typodont rather than the individual model. The Navident system offers a head gear-type patient tracker or the JawTag, and during pre-planning trials, the author felt the trackers were not secure enough and could drastically skew the data due to repeated re-calibration. Once the desired location is approached by the bur within 3mm, the target appears on the screen and informs the operator in real time of deviations from the planned location, angulation, and depth(Figure 11). Once oriented and ready to begin the access, a new timer was started for the time of the initial access to locate and orient to the impacted canine. This time to perform the initial access and locate the canine(Time to Locate- TL) was tracked and recorded. All access and uncovery procedures were performed with an 8 round carbide bur.

A second CBCT (CBCT2) was captured to measure the volume of the initial access(VI) (Figure 11). Given that guided navigation only allows planning of straight-line access, the

Navident was only used for the initial access osteotomy, then finalized with the traditional freehand approach. Next, the osteotomy was refined for complete uncovery of the impacted canine. The time to finalize and finish the osteotomy (Time to Finalize-TF) and volume of the final osteotomy(Volume Final-VF) were collected again. The time to finalize (TF) was measured with a stopwatch starting once the operator resumed the uncovery process of the canine, and stopped once the canine no longer had plastic obstructing the previously covered crown. A third and final CBCT (CBCT3) was captured to measure the final volume of the uncovery(Figure 12).

Time Assessment

The time to plan and prepare for both procedures and time to access and expose the canine prior to initiation of the access(Time to Prepare-TP). The timing of all procedures was performed with stopwatch(Apple iPhone X, Apple Inc. Cupertino CA, USA), as outlined below.

The TP for the traditional free-handed method included tracing the jaw arch in the correct axial plane through the impacted canine, as well as, measuring in the correct sagittal plane from a unique landmark to the impacted canine for orientation and positioning to initiate access(Figure 13). Carestream CBCT viewing software was used for this process for all traditional freehand trials. The time to plan/prepare(TP) was tracked with a stopwatch, starting at the opening of the CBCT scan and stopping once the operator was ready to begin the access. Given that guided navigation only allows planning of straight-line access, the Navident was only used for the initial access osteotomy, then finalized with the traditional freehand approach.

The osteotomy was refined for complete uncovery of the impacted canine. The time to finalize and finish the osteotomy (Time to Finalize-TF) and volume of the final osteotomy (Volume Final-VF) were collected again. The time to finalize (TF), was tracked with a stopwatch starting once the operator resumed the uncovery process of the canine, and stopped once the canine no longer had plastic obstructing the previously covered crown.

Radiographic Analysis

The first CBCT was taken after models were poured and finalized(Figure 5). A second CBCT was captured to measure the volume of the initial access(VI) (Figure11). A third and final CBCT was captured to measure the final volume of the final osteotomy (Volume Final-VF) (Figure 12) following refining osteotomy for complete uncovery of the impacted canine.

Volumetric Analysis

A total of three CBCT scans were taken using Carestream Cone Beam CT scanner (CS-8100D, Carestream Dental LLC, Atlanta, GA, USA.) at 60kVp and 2mA with the Voxel size of 150µm. All scans were analyzed with the ITK/SNAP DICOM viewer (http://www.itksnap.org/download/snap/), an open source medical image computing platform for biomedical research. Manual segmentation tool was used to segment the osteotomy opening on the right and left side. Images were evaluated in the axial, coronal and sagittal planes. With manual segmentation paintbrush tool, standard brush size of 5 was used to mark the consistent thickness of the voxels of the osteotomy opening. For each access on each model, two end points of the walls of the osteotomy sites were connected by the paintbrush marking and were confirmed in the all three planes for accuracy. Interpolation tool was then used to fill any gaps between markings due to the non-orthogonal nature of the anatomy. Software then automatically analyzes volume in mm3 and provides the 3D rendering of the osteotomy opening in the form of a 3D-disc.

Statistical Methods

Two-way ANOVA models were used to test for differences in time and volume based on the side of the jaw (left vs. right) and the method (traditional freehand vs guided navigation). An interaction term allowed for differences in the effect of the method based on the side of the jaw. Post hoc pairwise comparisons were performed with Tukey's adjustment to account for multiple comparisons. SAS EG v.8.2 (SAS Institute, Cary, NC) was used for all analyses. Significance level was set at 0.05.

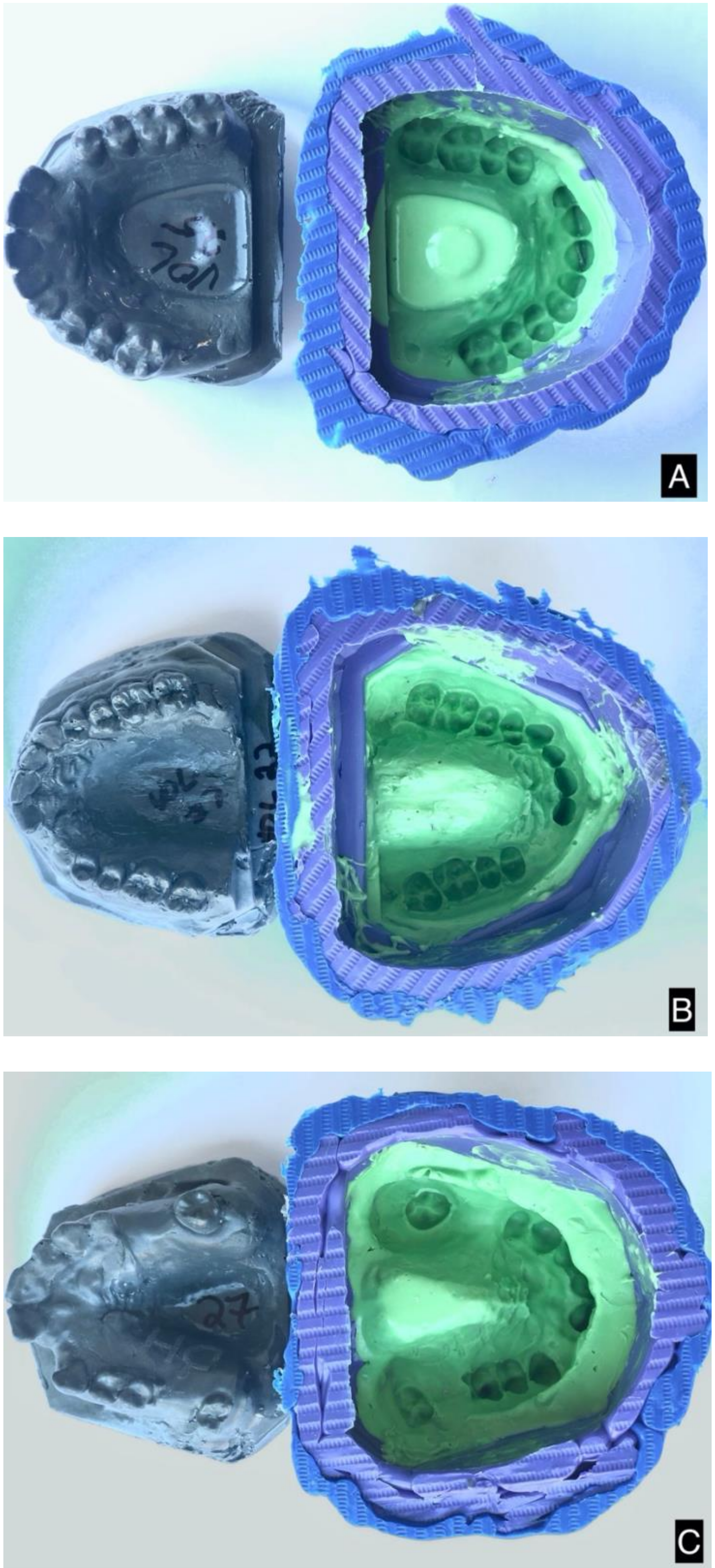


Figure 1. PVS molds to duplicate three maxillary model types(A, B, C) utilized in the study.

Figure 2. Alumilite White Casting Resin-Two-Part Liquid Urethane. B08R5DB56

Figure 3. Iron Powder. EnvironMolds, LLC, ArtMolds Fine Iron(Fe) Powder Very Fine 320 Mesh +/- P/N SM400241R.

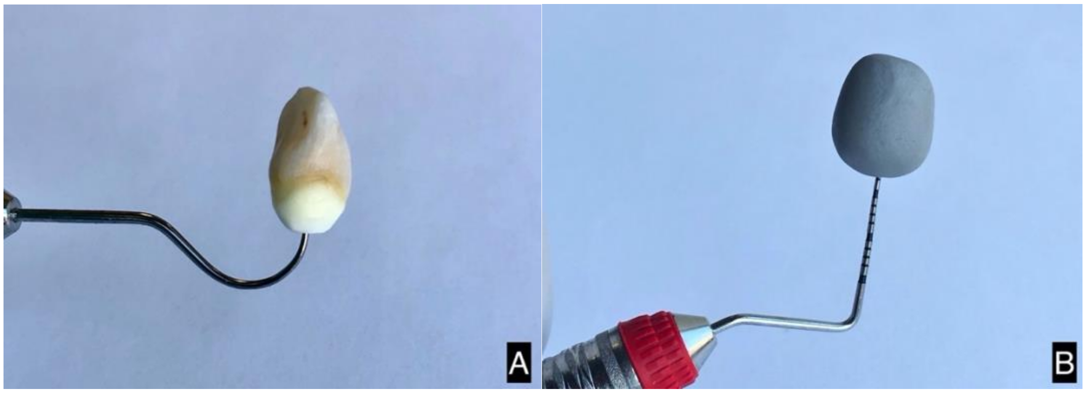


Figure 4. Crown of natural canine used to simulate impacted tooth (A) wrapped in molding clay to simulate a dental follicle (B).

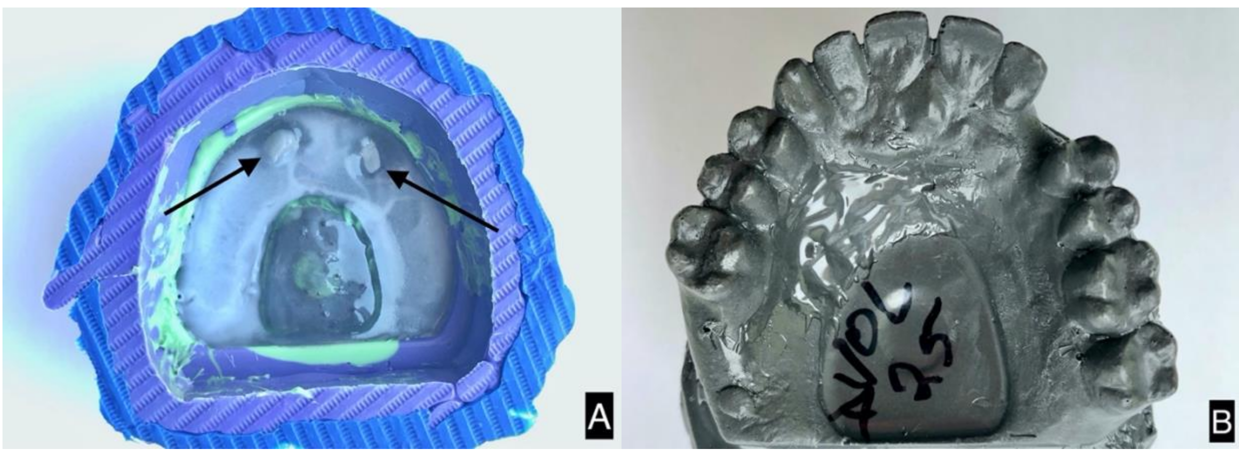


Figure 5. Impacted canines positions indicated by black arrows (A), located in roughly canine areas of molds. Final replicated model ready for CBCT scan (B).

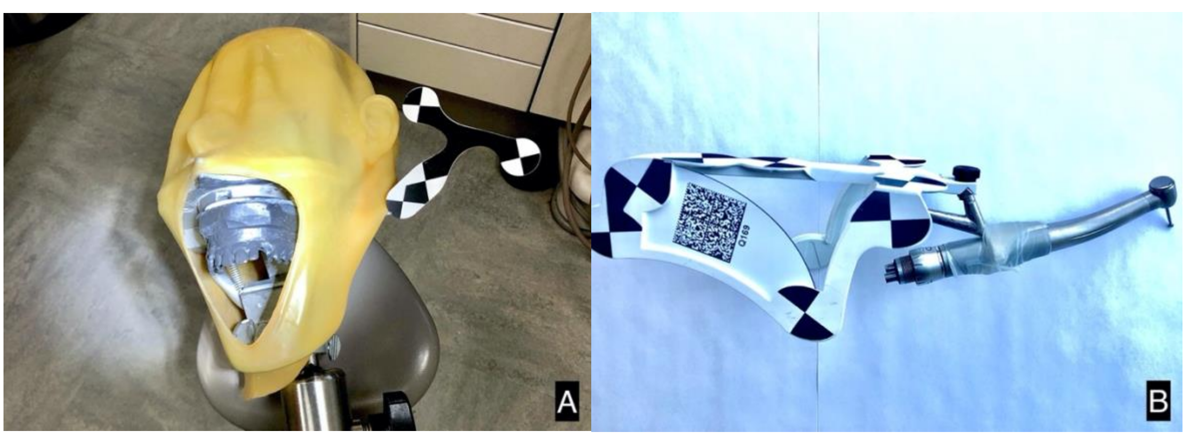


Figure 6. JawTag was attached to the typodont (A), and handpiece-tag with recognition patterns (B).

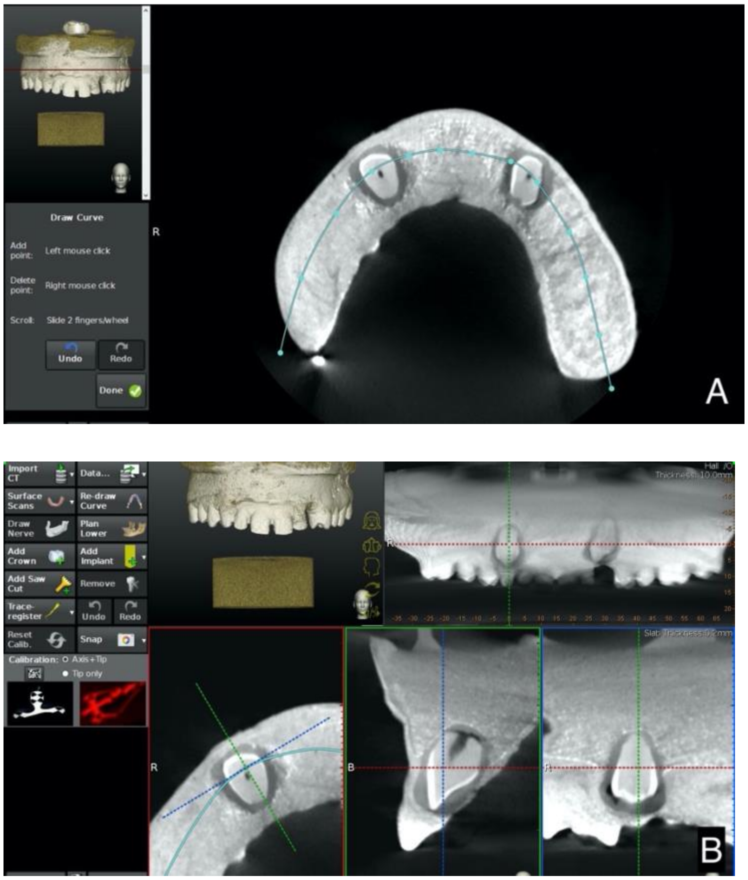


Figure 7. Navident software: tracing of maxillary arch (A), and identification of location of impacted canines (B).

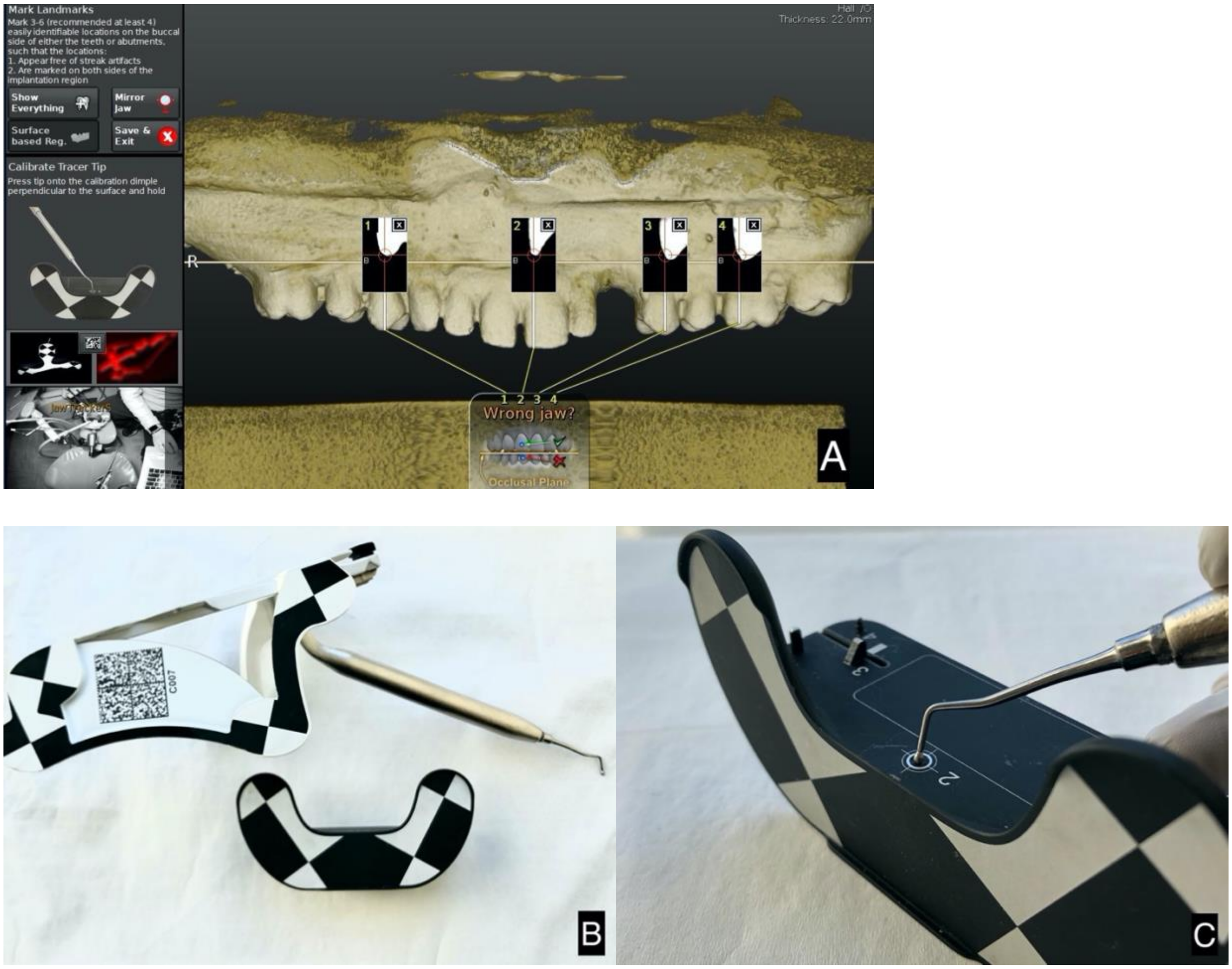


Figure 8. Model tracing in Navident software (A) using Tracer tool and calibration tool(B). The same calibration tool is used for both the Tracer and handpiece calibration(C).

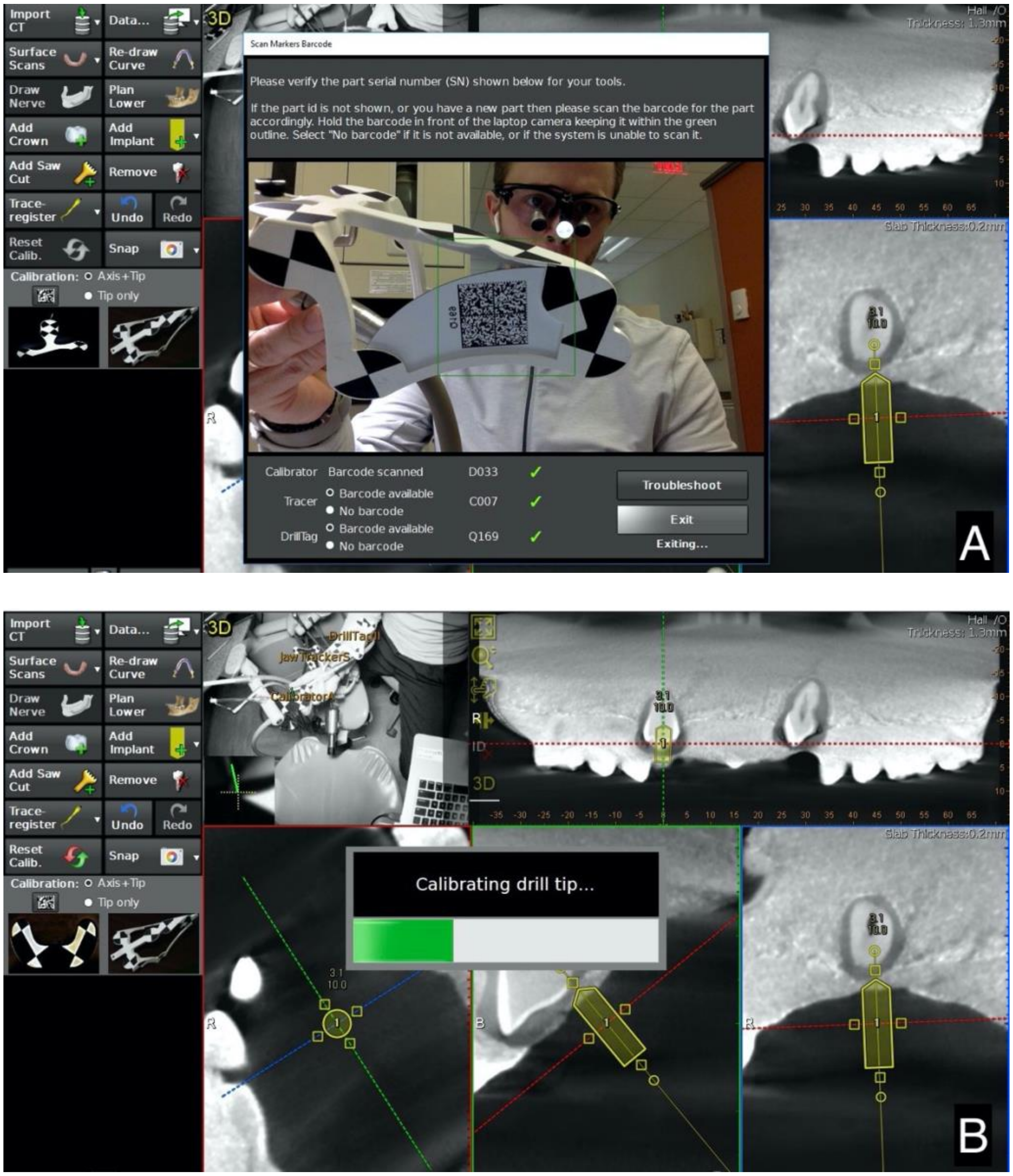


Figure 9. Each handpiece or tracer tool has a unique QR code recognized by the Navident system (A). Bur length, drill axis of rotation are calibrated for each trial (B).

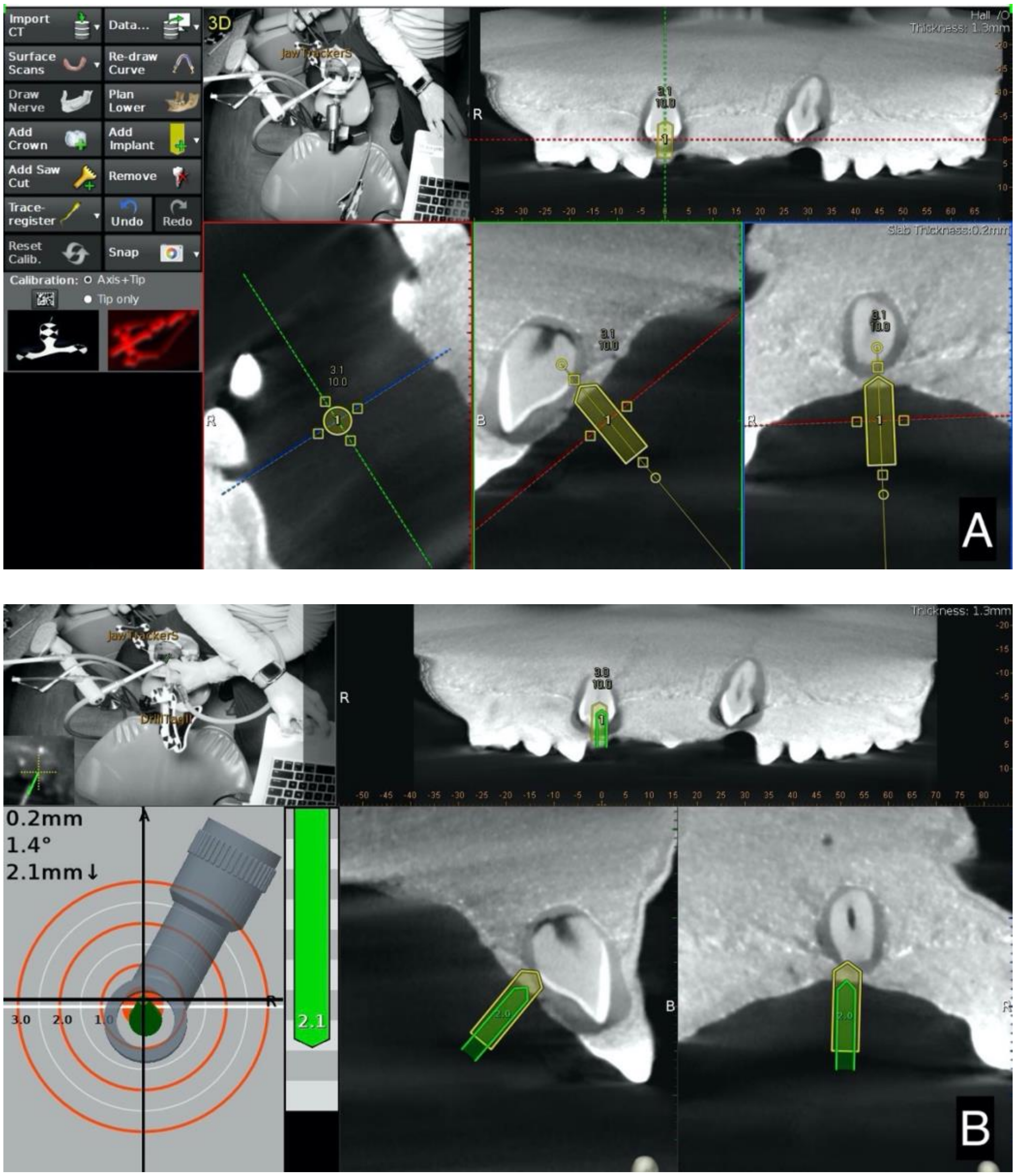


Figure 10. Planned osteotomy access (A) with Real-time positional feedback on virtual display (B).

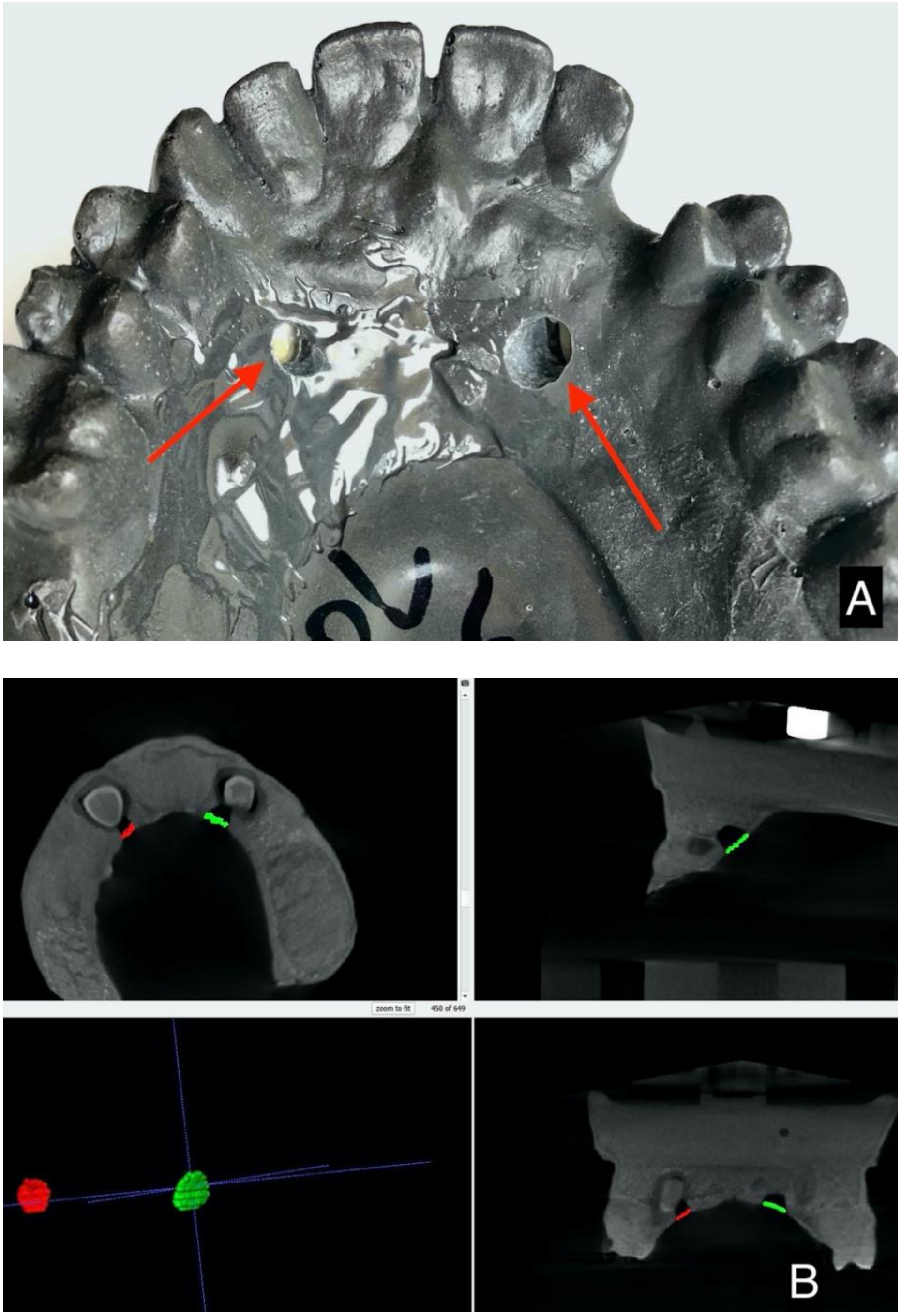


Figure 11. Red arrows point to Initial Access preparation (A), and Volumetric analysis of initial access preparation on CBCT 2 (B).

Figure 12. Clinical appearance of Final Access preparation (A), and Volumetric analysis of final Access preparation on CBCT 3 (B).

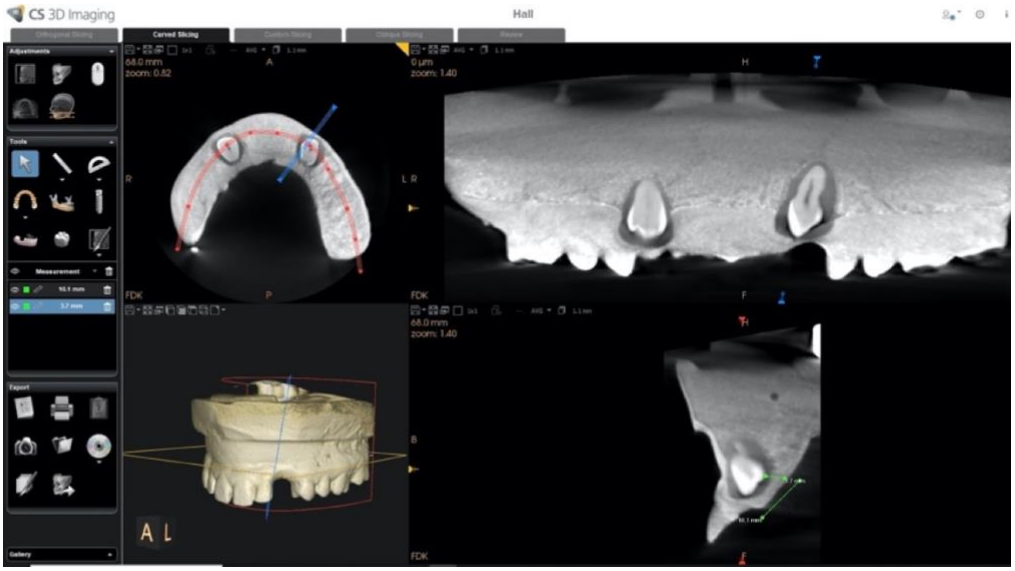


Figure 13. Carestream CBCT software used for freehand approach for osteotomy access.

Results

Bilaterally palatally impacted canines were exposed either with the freehand or with guided navigation approach in 18 models, a total of 36 sites evenly distributed. Average procedure times and volume measures are presented in Table 1. Summary of Average Times and Volume Analysis by Method (Mean, SD).

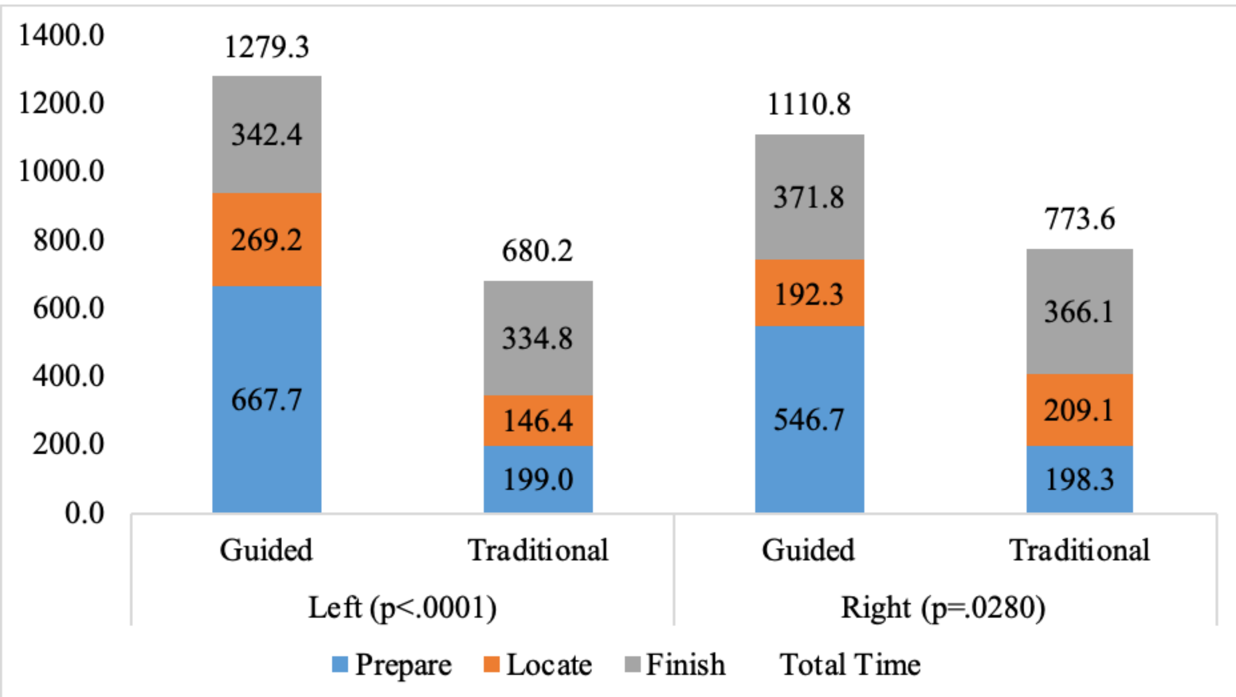
Table 1. Summary of Average Times and Volume Analysis by Method (Mean, SD)

	Freehand	Guided
Time (s)		
Prepare	198.7, 52.93	607.2, 225.02
Locate	177.8, 95.58	230.8, 99.77
Finish	350.4, 101.8	357.1, 83.81
Total Time	726.9, 158.29	1195.1, 307.82
Volume (mm^3)		
Entry	13.1, 5.70	8.6, 2.97
Final	77.4, 14.90	78.9, 16.39

*SD=Standard Deviation

The time to prepare for the procedure was significantly longer for the guided navigation experiments ($p<.0001$). Preparation time was on average 10:07 for guided navigation and 3:19 for freehand. The time to locate the tooth was significantly different on the left side of the models with guided taking approximately 2 minutes longer than freehand (122.78s; p=.0423) but did not differ significantly on the right (16.78s longer for freehand; p=.9809). The time to finish the procedure did not differ significantly based on the method (p=0.8342) or the side of the model (p=.3441). The total time was significantly longer for the guided navigation (7:48; p<.0001). Figure 14 displays the average time for each portion of the procedure along with the total time by both side and method.

Figure 14. Average Procedure Time by Side and Method (seconds).



Based on a volumetric assessment, the size of the initial osteotomy was significantly smaller for guided navigation on the right side of the models by an average of $7.13mm^3$ (adjusted p=.0097). The difference on the left side of the models was not significant ($1.86mm^3$, p=.9933). Figure 15 displays the average entry volume by method and side of the jaw. The total volume removed did not differ significantly between the two methods (78.9 vs 77.4 mm^3; p=.7793) or on the side of the model (79.1 vs 77.2 mm^3, p=.7175). Figure 16 displays the average total volume removed by method and side of the jaw.

Figure 15. Average Entry Volume by Side and Method.

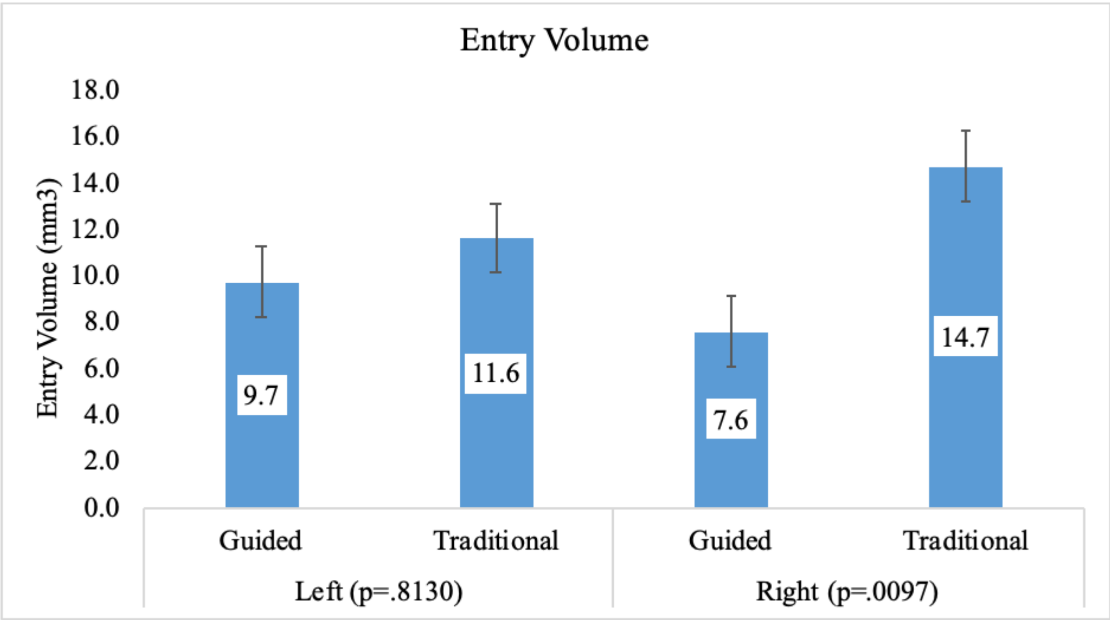
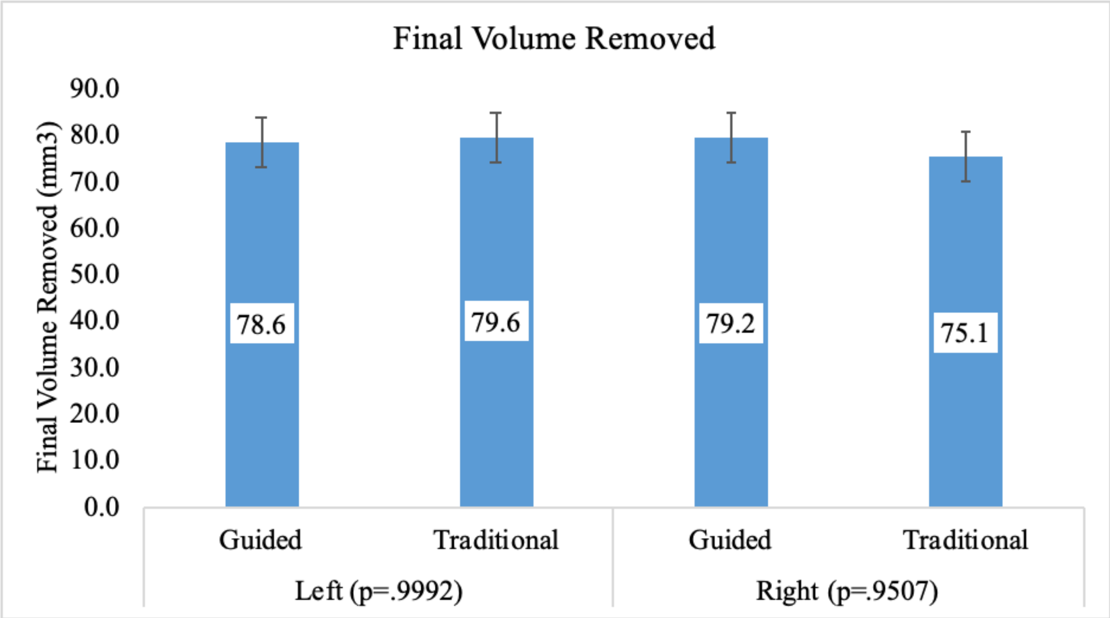


Figure 16. Average Total Volume Removed by Side and Method.



Discussion

The purpose of this study was to investigate the application of dynamic navigation for use in surgical exposure of palatally impacted canines. In addition to evaluating the feasibility of its application, the investigators also measured and compared the differences in the time needed to plan and perform uncovery of maxillary impacted canines and the differences in the size of the osteotomies to access and uncover the canines.

This study did not compare positional differences between planned and final locations as in traditional applications, but rather compared the access size accomplished with dynamic navigation to that achieved with the freehanded approach. Our volumetric analysis revealed the average initial access sizes on the right side were 7.6mm^3 for guided and 14.7mm^3 for traditional freehand. This difference was significantly smaller for guided navigation on the right side of the models by an average of 7.13mm^3(adjusted p=.0097). On the left side, the average access volumes were 9.7mm^3 and 11.6mm^3, for guided and traditional, respectively. This difference still favored dynamic navigation as more precise, direct and less invasive approach but was not statistically significant (1.86mm^3, p=.9933). This finding can likely be attributed to direct visualization on the left hand side for a right handed operator, versus the right side which may be more difficult to visualize with freehand approach but is not affected by computer guided dynamically navigated approach.

Our findings support that dynamic navigation could be used for the sites with difficult visualization and demonstrates quantitatively the differences in access osteotomy size. Figure 15 displays the average entry volume by method and side of the jaw. To the best of the author's knowledge, this is the first application of this technology for the purpose of uncovering palatally impacted canines. As such there are no other present studies available for direct comparison, so our best effort was made to extrapolate relevant findings and how they may be applied.

These findings could be interpreted in several ways. First, with less than adequate visualization for a right-handed operator, the dynamic navigation allows a more controlled precise access in more difficult operator conditions. This assistance of guidance is exemplified in a significantly smaller osteotomy and significant differences in volume sizes. Alternatively, the left side did not have a significant difference because the operator has better visualization of the surgical site, and is able to adjust and refine positioning accordingly. Thus, less guidance is needed to achieve similar osteotomies, and the resulting access volumes were not significantly different in size. Given previous findings with dynamic navigation, the author is inclined to interpret these findings as more accurate, and therefore safer for the location of the impacted canine in less than ideal circumstances. A recent study evaluating the training of dental students to place implants using dynamic navigation, found the maxillary left sites were less accurate than contralateral right-sided sites.[37] Their assessment was attributed to working across the arch, angulation and accessibility, which is in line with what was experienced in this study as well. Subjectively, the operator did note that it was more difficult to maintain the orientation of the JawTag and handpiece Tag within the tracking field of view for the left side. Following a similar protocol to a study by Deeb[37], the Jawtags were attached permanently in one position to the typodont, permitting the study models to be changed out, without repositioning of the JawTag no matter the location of the surgical site. This most certainly would have increased the time for planning of the dynamic Navigation group, as well as, influenced the ease of use of the JawTag-Tracker interaction that is so critical for Dynamic Navigation. This variable was not evaluated or accounted for in this study model.

Previous work has demonstrated that fully dynamically guided implant placement is more accurate than freehand implant placement in multiple planes of orientation including angular deviation, platform positioning, and apical positioning.[38] The use of dynamic navigation has also been studied in the field of endodontics showing benefits in tooth structure conservation and better accuracy in finding calcified canals.[39–41] As shown in the aforementioned studies, dynamic navigation can help direct or guide the operator to a predetermined destination with significant accuracy and a smaller access field. It was the authors' presumption that this technology could be used to navigate in a minimally invasive fashion to a palatally impacted canine tooth and translate into an overall smaller final volume of the resulting surgical site. Based on our volumetric assessment, this study found that the size of the initial osteotomy was significantly smaller for guided navigation on the right side of the models, but no significant difference on the left side, but the total volume removed did not differ significantly between the two methods (78.9 vs 77.4 mm^3; p=.7793) or on the side of the model (79.1 vs 77.2 mm^3, p=.7175). Figure 16 displays the average total volume removed by method and side of the jaw. Using dynamic navigation for maxillary canine exposure allowed the operator to locate and orient himself clinically to the position of the impacted tooth. This guidance however is essentially in a straight line, as seen in osteotomy preparation. Once the initial access is completed, the operator must continue to expose the impacted tooth using the freehanded method to ensure all bone or follicular structure that may impede the canine's movement is removed. It must be noted that while it is possible to plan several small osteotomies to encircle the impacted canine and remove all needed tissue, this is impractical and not really of any value to a clinician. Thus, in this study after finalizing the uncovery with freehand drilling, although the initial size of the access was smaller for dynamic navigation, we found that the final size of the structure removed was not significantly different between the two methods.

Based on our findings one could advocate for a dynamic navigation method in clinical situations with close proximity to vital structures, adjacent roots or deep impactions with rotated teeth. Accuracy and precision of the initial access and location of the tooth appear to be the main benefit associated with this application of the technology. However, it is more time-consuming and this study found the final size of material removed to be similar between the two methods. Previous studies evaluating the operator learning curve found only slight improvements in time and accuracy of implant placement with dynamic navigation between the second and third attempts.[37] Computer-guided simulation is used in other surgical fields such as laparoscopy and endoscopy, for training and evaluation of surgical capacity and has demonstrated a learning curve and improvement with more training as well.[42–44] In this study, all attempts were performed by the same operator, but no analysis was performed to evaluate improvements within the conducted trials.

If the accuracy and precision of the dynamic navigation is its strength, the additional time needed in preparation for its use is its weakness. Both methods of exposure were timed from the initial opening of the CBCT file until the operator had familiarized himself with the surgical site and prepared the appropriate access approach. The time to prepare for the procedure was significantly longer for the guided navigation experiments ($p<.0001$). Preparation time was on average 10:07(min:sec) for guided navigation and 3:19 (min:sec) for freehand.

In this study, the time to locate the tooth was significantly different on the left side of the models with guided taking approximately 2 minutes longer than freehand (122.78s; $p=.0423$), but did not differ significantly on the right (16.78s longer for freehand; $p=.9809$). This finding seems to align with the volumetric data, suggesting that the left side is more difficult for a right-handed operator, therefore, taking more time and resulting in a larger, less precise access. Following the initial access, a new CBCT was taken for volumetric analysis, and a timer started again for the operator to completely uncover the impacted canine (Time to Finalize- TF). The final uncovery was performed solely using the freehanded method. The time to finish the procedure did not differ significantly based on the method ($p=0.8342$) or the side of the model ($p=.3441$). The total time was significantly longer for the guided navigation (7:48; $p<.0001$).). Figure 14 displays the average time for each portion of the procedure along with the total time by both side and method.

A limitation of this study was in the models utilized and the inability to raise a mucoperiosteal flap which would have added time to the traditional surgical uncovering procedure. Using the dynamic navigation approach and a precisely planned access to the tooth, a surgeon may feel more confident in the planned surgical approach and may choose to pass directly through the palatal tissues to uncover the tooth without raising a flap. With the traditional approach lacking this precise access to the tooth, the elevation of the flap is inevitable. Surgical access without a flap would reduce the overall time of the procedure and decrease postoperative morbidity. An orthodontic chain can be passed through a window or tunnel made through ablated palatal tissues if tooth position can be accurately and predictably accessed.[27]

Conversely, if a mucoperiosteal flap is raised to locate and expose the impacted tooth, the procedure affects a much larger area, requires larger area of local anesthesia, longer time to elevate the flap and suture it back, and leads to higher intraoperative bleeding and post-operative morbidity. Other authors have proposed a periodontal packing is placed to prevent tissue overgrowth, and for it to be removed after about a week to place a traction chain.[27,32,45]

The total time of the procedures studied here are within the reported ranges in the literature. Access to palatally impacted canines required a mean of 726.9s (or 12.1min.) and 1195.1s (or 19.92min) for freehand and dynamic navigation, respectively. Although not a direct comparison, another study reported operating time for a closed eruption technique took on average three times longer than the open method, although no detailed description was noted on what portions of the procedure were included in their timing measurements. They reported mean operating times of 36 min(range, 27-43 mins) and 12 min(range, 9-22) for closed and open, respectively.[25] A potential drawback to not reflecting a full-thickness mucoperiosteal flap and complete visualization of the palatal bone could be insufficient osseous removal. Crowns do not contain the cells necessary to resorb bone and the crowns may move very slowly or not at all, giving the appearance of ankylosis. Complete visualization of the surgical site also allows the surgeon to provide insight to their referring orthodontist based on their clinical observations. Woloshyn noted that when canines were moved across the lingual surfaces of the adjacent incisors, resorption of the roots may occur.[46] In these scenarios, when compared to the non-impacted contralateral teeth, attachment and bone levels are located more apically on the mesial of the previously impacted canine and the distal of the lateral incisor.[46] The alignment of impacted maxillary canines is a risk factor for resorption of the lateral incisor.[47] The periodontal health of palatally impacted canines has been the subject of several studies.[31,33,48,49] Clinical studies have shown that when a conservative surgical technique is used and the periodontium is kept healthy, there is no loss of periodontal attachment during orthodontic tooth movement.[50,51]

There are several recognized limitations to this study. As previously mentioned, the JawTag was fixed to the typodont rather than individual models, as well as no simulation of soft tissue for mucoperiosteal flap elevation, both of which influenced the times necessary for each procedure. Additionally, the same operator performed all of the canine procedures. Future studies could examine the learning curve present for dynamic navigation in canine exposure.

Conclusion

Within the limitations of this study, dynamic navigation methods require more time to prepare prior to initiation of surgery, as well as to locate the impacted canine on the left side of the palate, for a right handed operator. Initial access volume was significantly smaller with dynamic navigation on the right side, but the benefit was not seen on the opposite side. No significant differences were seen in the time to finalize the osteotomy or the final size. Dynamic navigation could add significant value to a surgeon in certain clinical presentations, such as proximity to vital structures and adjacent roots, despite the increased time for preparation.

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