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Accuracy of computer-assisted dynamic navigation when performing coronectomy of the mandibular third molar: A pilot study

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ABSTRACT

Objectives: The study represents a preliminary evaluation of the accuracy of the dynamic navigation system (DNS) in coronectomy of the mandibular third molar (M3M).
Methods: The study included participants with an impacted M3M near the inferior alveolar canal. The coronectomy planes were designed before the surgery using cone-beam computed tomography (CBCT) imaging data and then loaded into the DNS program. Intraoperatively, the navigation system was used to guide the complete removal of the target crown. Postoperative CBCT imaging was used to assess any three-dimensional deviations of the actual postoperative from the planned preoperative section planes for each patient.
Results: A total of 12 patients (13 teeth) were included. The root mean square (RMS) deviation of the preoperatively designed plane from the actual postoperative surface was 0.69 ± 0.21 mm, with a maximum of 1.45 ± 0.83/-1.87 ± 0.63 mm deviation. The areas with distance deviations < 1 mm, 1–2 mm, and 2–3 mm were 71.97 ± 5.72 %, 22.96 ± 6.57 %, and 4.52 ± 2.28 %, respectively. Most patients showed extremely high convexity of the surface area located in the mesial region adjacent to the base of the extraction socket. There was no observable evidence of scratching of the buccolingual bone plate at the base of the extraction socket by the handpiece drill.
Conclusions: These results provide preliminary support for the use of DNS-based techniques when extracting M3M using a buccal approach. This would improve the accuracy of coronectomy and reduce the potiential damage to the surrounding tissue.
Clinical significance: DNS is effective for guiding coronectomy.

1. Introduction

Injury to the inferior alveolar nerve (IAN) can occur during extraction of the mandibular third molar (M3M) [1]. The use of coronectomy instead of conventional extraction procedures can reduce the risk of IAN injury. Coronectomy involves transection and removal of the crown while preserving the root, thus avoiding the risk of injury to the IAN [2]. Póvoa reviewed the advantages and disadvantages of M3M coronectomy, concluding that coronectomy was associated with an IAN injury rate of 0.59 %, which was significantly lower than traditional M3M extraction surgery [3]. Studies by Yan et al. and Leung et al. also demonstrated that coronectomy could reduce the risk of IAN injury during surgery [4,5]. In addition, compared with tooth extraction surgery, coronectomy has significant advantages in terms of reducing both postoperative pain and dry socket syndrome, together with no increase in the incidence of postoperative infection [6,7].

However, there are two factors that may lead to the failure of coronectomy. The first is postoperative root movement or even eruption, necessitating a second surgery [8]. It has been reported that 65–97 % of residual roots move after coronectomy [9,10]. Yan's study showed that the patient's age, the degree of angulation of the M3M, and the depth of the impacted M3M were factors affecting tooth root movement.

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Improving the accuracy of the surgery and ensuring that the remaining root is <7.6 mm in length and at least 5 mm below the bone margin might reduce movement of the remaining root after coronectomy [11]. Another factor affecting the success rate of coronectomy is the presence of residual enamel after surgery. However, the use of a dental drill to remove the residual enamel can prolong the duration of the procedure while exposing patients to a greater risk of damage to the IAN, lingual nerve, and other surrounding tissues [12]. Local anatomical variability and limited surgical visualization may also affect the accuracy of the coronectomy procedure and the incidence of postoperative complications.

The dynamic navigation system (DNS) is a surgical instrument that can enhance intraoperative precision. Since their first development in the 1980s, navigation technologies have been extensively utilized in dental treatments, particularly in the field of implant surgery. These technologies have played a significant role in increasing the accuracy of operative outcomes [13,14]. Dynamic navigation technologies have also recently been used for endodontic procedures, revolutionizing the accuracy of apical surgery and root canal operations [15–19]. DNS applications have been repeatedly confirmed to decrease the technical sensitivity of these treatments while improving the associated operative accuracy.

Currently, the application of DNS technologies in tooth extraction has been largely restricted to the removal of maxillary supernumerary teeth [20,21]. To date, only two articles specifically addressing the use of DNS for M3M extraction procedures have been published [22,23]. This limited number of studies may be attributed to the lack of available comprehensive guidelines for navigation-assisted extraction surgery. The surgical operating space in the retromolar area is much smaller than that in the anterior area. Therefore, the application and accuracy verification of DNS in the retromolar region are very challenging. The primary objective of the present study was to devise a methodology for the navigation-assisted coronectomy of M3Ms and evaluate the precision of this approach.

2. Materials and methods

2.1. Participant recruitment

This pilot study was conducted as part of an ongoing study focused on the procedural precision of navigation-guided coronectomy. The Institutional Review Boards of Peking University School and Hospital of Stomatology approved this study (Approval Number: PKUSSIRB-202277083) and the study was conducted in accordance with the Declaration of Helsinki (2013 revision). Written informed consent was obtained from all patients before study participation (Clinical trial registration number: ChiCTR2200062544).

Patients eligible for inclusion were those aged between 18 and 40 years of age with impacted M3Ms and CBCT images showing a close relationship between the M3M roots and the mandibular nerve canal, who requested extraction and agreed to undergo coronectomy.

Patients were excluded from this study if they had systemic diseases, immune disorders, had used hormonal drugs or antibiotics in the three months before the extraction, had caries, apical lesions, or cystic lesions of the M3Ms, had a history of mandibular radiotherapy, had trouble keeping the reference device in place (for example, because they had severe periodontitis or missing teeth), or showed root loosening during coronectomy.

2.2. Preoperative design

2.2.1. Cone-beam computed tomography and intraoral scanning

The U-shaped tube registration device was securely attached to the mandibular dentition on the operating side using silicone rubber. Subsequently, full-arch cone-beam computed tomography (CBCT) scanning was conducted for all patients using a CS 9300 unit (Carestream Health, Atlanta, GA, USA). CBCT scanning was performed using the specified settings of 90 kV, 8 mA, 8 s, and a voxel size of 180 μm. The resultant Digital Imaging and Communications in Medicine (DICOM) data were imported into Mimics™ 19.0 (materialise Dental, Leuven, Belgium), followed by the calculation of models of the third molar, bone, and mandibular dentition in the standard tessellation language (STL) format. Patients also underwent intraoral optical scanning (IOS; Trios3, 3Shape, Copenhagen, Denmark). The resultant CBCT and IOS scans were superimposed using GeoMagic™ Studio 12 software (3D Systems, SC, USA).

2.2.2. Selection of the sectioning plane

The classical coronectomy procedure was first outlined in 2004 [2]. Firstly, the Initial plane was defined and the crown was transected starting from the buccal plate crest in accordance with this plane. The remaining crown was then trimmed until a second plane was reached (referred to herein as the Final plane). The Final plane requires the removal of all the enamel. In addition, the remaining roots should be ≥ 3 mm below the crest of the lingual and buccal plates in all areas. Liu et al. suggested that the pulp chamber floor of the mandibular first molar should be positioned 1–2 mm below the enamel-cementum boundary [24], providing a potential reference for the selection of the optimal sectioning plane when performing the coronectomy procedure. Usually, the comprehensive elimination of the enamel is accomplished by the removal of the tooth tissue situated above the bottom of the pulp chamber. To accomplish this, a final plane perpendicular to the longitudinal axis of the tooth and intersecting with the lowest point of the pulp chamber floor was established. Furthermore, an additional plane known as the Indication plane, oriented perpendicular to the longitudinal axis of the tooth, and intersecting with the highest point of the buccal bone plate, was established to signify the start of the Initial plane. The selection of the Initial plane was finally determined using both the Final and Indication planes (Fig. 1A).

2.2.3. Surgical path planning

After the definition of the sectioning planes as described above, the STL file for the mandibular dentition using these planes was imported into the Dcarer® dynamic navigation and superimposed on the CBCT images (Fig. 1B**, C**). The guiding grooves were designed to indicate the position for drill entry. There were three groups of guiding grooves, located on the Initial plane. This meticulous preparation facilitated the identification of optimal drill entry points, as well as the determination of appropriate angles, diameters, pathways, and depths (Fig. 2A**-C**). A coarse-diameter cylindrical alignment groove (guiding groove) was also established such that its bottom was positioned on the Final plane, allowing the operating surgeon to determine when the correct depth had been reached (Fig. 2D**-F**).

2.3. Surgical procedures

2.3.1. Calibration and registration

Calibration and registration were performed before the surgery [25,26]. Handpiece calibration was performed with a handpiece locator and reference device equipped with infrared transmitters capable of transmitting signals to the navigator, thereby enabling effective spatial localization. The handpiece was equipped with consecutive long and short ball drills, and the tip of the drill was precisely determined near a hemispherical groove present on the reference device. The navigator then assessed the positions of the handpiece and reference devices to acquire information on the relative positional interconnections between the devices.

For subsequent registration, a reference device with a fixation device was affixed to the opposite side of the mandible using self-curing resin (DMG Chemisch- Pharmazeutische, Germany). The U-shaped tube registration device was reset in the mouth, after which the handpiece was equipped with a short ball drill and used to gather specific ball pit

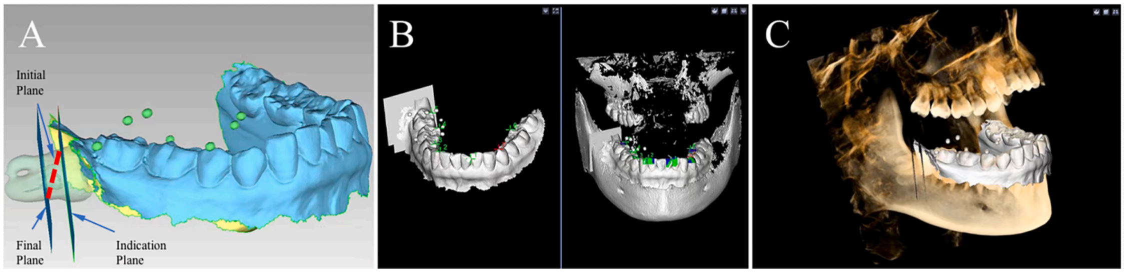

Fig. 1. (A) Determination of the positioning of the Indication, Initial, and Final Planes. (B) The process of importing the designated planes into the DNS system and matching them with the CBCT images. (C) Matching between the designed planes and the CBCT images.

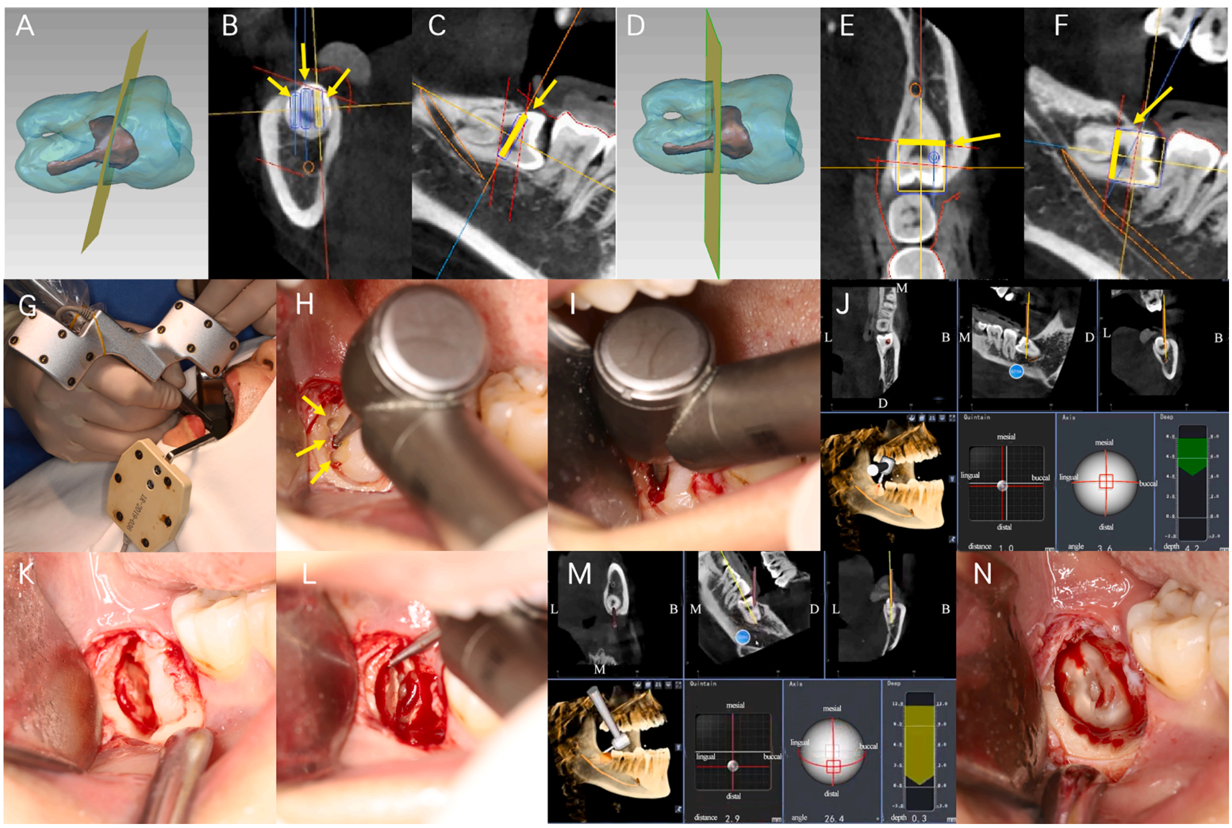

Fig. 2. (A-C) Determination of the positioning of the Initial Plane. Alignment grooves (guiding grooves) are indicated with arrows. (D-F) Determination of the positioning of the Final Plane. Arrows represent the Final Plane. (G) The coronectomy procedure was performed using a DNS approach. (H) Determination of the entry position for the alignment grooves (arrows). (I, J) The bur was drilled in the three designated alignment grooves in the appropriate position and direction until reaching the required depth under DNS-mediated guidance. (K) After obtaining the Initial Plane, the overlying crown was removed. (L, M) The root was trimmed under DNS-mediated guidance until obtaining the Final Plane. (N) The final sectioning surface.

details for 6 marker points using the U-shaped tube registration device. This information allowed the determination of the relative spatial positions of the handpiece, reference device, virtual CBCT images, and jaw position. After the registration process, the U-shaped tube apparatus was extracted, and the precision of registration was assessed by positioning a drill at the apex of the tooth's cusp. The use of this system allowed visualization of the drills in real-time and in three dimensions during the surgical procedure (**Fig.** 2 G). The calibration and registration time before surgery (from the beginning of calibration to the beginning of incision) was approximately 10–15 min.

2.3.2. Guided coronectomy procedures

Intraoperative IAN-block and local infiltration anesthesia were performed simultaneously using 4 % Articaine (1:100,000 adrenaline) (Primacaine TM, France). A three-sided full-thickness mucoperiosteal flap with an anterior vertical incision was positioned distal to the mandibular second molar. The buccal and distal bones were removed to expose the buccal cementoenamel junction. The high-speed handpiece provided guidance to the operator for the accurate drilling of the bur into the three designated alignment grooves (guiding grooves) (Fig. 2H), drilling in an appropriate direction until reaching the designated depth (Fig. 2I**, J**). The tooth tissue between these three guiding grooves was then manually removed to yield the Initial plane, with full separation of the overlying crown from the root (Fig. 2K). The DNS system was then used to trim the remaining tooth until it reached the ideal depth (Fig. 2L**, M**), yielding the Final plane (Fig. 2N). Primary suturing was performed after the coronectomy. The approximate operation time (from incision to the completion of suturing) was 30–40 min. All surgical procedures were performed by the same practitioner. All patients were prescribed antibiotics for three days post-operatively.

2.4. Outcome evaluations

After completion of the surgical procedure, repeated CBCT imaging was conducted and images of the mandibular dentition and remaining M3M roots were imported into GeoMagic software in the STL format. The "Best-Fit Alignment" algorithm was employed to register the preoperative model with the postoperative model, utilizing distinct anatomical markers [27]. Using the plane developed preoperatively as a reference and the postoperative remaining root for comparison, geometric deviations between the two models were assessed using the "Deviation" algorithm. This resulted in a colored map, allowing the determination of the root mean square (RMS) of the deviation, as well as the proportions of the overall area with different degrees of deviation [28]. The most concave and convex areas on the postoperative tooth surface were also assessed qualitatively (Fig.3A, **B**). Data were reported as means ± standard deviation, and descriptive statistical analyses were performed.

We also followed up and observed the clinical healing in the patient one week, one month, and three months after treatment. The assessments included the presence of sensation disorders in the lower lip, postoperative infections, symptoms of pulpitis, dry socket, and postoperative root eruption.

3. Results

Thirteen M3Ms of 12 patients (5 males and 7 females, with an age of 28.67 ± 2.35 years) were included in this study. There were no dropouts as of the three-month follow-up period. None of the patients experienced lower lip numbness. Similarly, no patients showed signs of postoperative infections, symptoms of pulpitis, dry socket, or postoperative root eruption. The majority of the included M3Ms were type A (type A, 6 M3Ms; type B, 4 M3Ms; type C 3, M3Ms, according to the Pell and Gregory classification) and were mesially (horizontal, 5 M3Ms; mesial, 6 M3Ms; vertical, 1 M3M; lingual, 1 M3M) impacted.

The RMS of the deviation of the preoperative designed plane from the actual postoperative surface was 0.69 ± 0.21 mm and the maximum deviation was 1.45 ± 0.83/−1.87 ± 0.63 mm. Areas with deviations < 1 mm, 1–2 mm, and 2–3 mm were 71.97 ± 5.72 %, 22.96 ± 6.57 %, and 4.52 ± 2.28 %, respectively. The surface area with the highest degree of convexity in most patients was located in the mesial region adjacent to the base of the extraction socket (Table 1). There was no observable evidence that the handpiece drill scratched the buccolingual bone plate or the base of the tooth extraction socket and caused a dent (Fig.4A, **B**).

4. Discussion

This pilot study is the first publication to date focusing on exploring the accuracy of DNS usage when conducting surgical procedures via a buccal approach in the posterior molar region. These data suggest that DNS technology as a technique that can improve the precision of coronectomy while lowering the potential risks to some extent. Additionally, these findings have implications for the more extensive use of this navigational technique for the extraction of difficult impacted or supernumerary teeth.

DNS-mediated assistance can improve the accuracy and efficiency of coronectomy procedures while lowering the risk of procedure-related trauma. The presence of residual enamel is the most common complication observed in patients undergoing coronectomy, potentially causing poor healing and the need for secondary extraction procedures. Previous studies suggested that the incidence of residual enamel after coronectomy ranged from 3.2 to 15 % [11,29,30]. All 13 crowns in this study were successfully removed without any residual enamel, emphasizing the accuracy of DNS-assisted coronectomy for M3M extraction. A common long-term complication of coronectomy is root movement, which may lead to secondary eruption and further surgical treatment of the remaining roots. Different studies have estimated the incidence of postoperative root movement to be between 65 % and 97 %, with the longest follow-up observation time of 12 years [9,10]. Yan's research suggests that accurate maintenance of the length of the remaining root within 7.6 mm is necessary to prevent re-eruption [9]. In this study, the root length in all 13 cases met the requirements accurately. Furthermore, it was observed that there were no observable dents present in the tooth extraction socket after trimming of the remaining root surface using handpiece drills. This suggests that the aforementioned technique may effectively reduce iatrogenic trauma to surrounding tissues caused by handpiece drills during coronectomy procedures. The RMS values were determined by calculating the discrepancy between the preoperative designed plane and the postoperative actual root surface in all 13 cases, which were subsequently averaged. Overall, 71.97 ± 5.72 % of the total areas showed deviations of less than 1 mm. This degree of deviation is similar to the accuracy that can be achieved when performing implant surgery with the assistance of a DNS [14,31,32], suggesting that this strategy provides an effective means of improving the accuracy of coronectomy surgery. No postoperative root eruption was observed in the first three months in any of the patients.

While these results are promising, there were nevertheless some positions in the patients with deviations exceeding 2 mm, greater than the reported deviations associated with DNS-assisted implant surgery [31,32]. The reason for this could be attributed to an adequate intermaxillary depth at the operational site for implant procedures. Additionally, the method involves the gradual preparation of holes, enabling an iterative verification of procedural precision. However, the posterior tooth area is less accessible than the anterior tooth area. Apical surgery assisted by DNS tools is rarely performed even in the second molar area [17]. When performing M3M coronectomy procedures from the buccal side, there are constraints on the operating area and vision may be

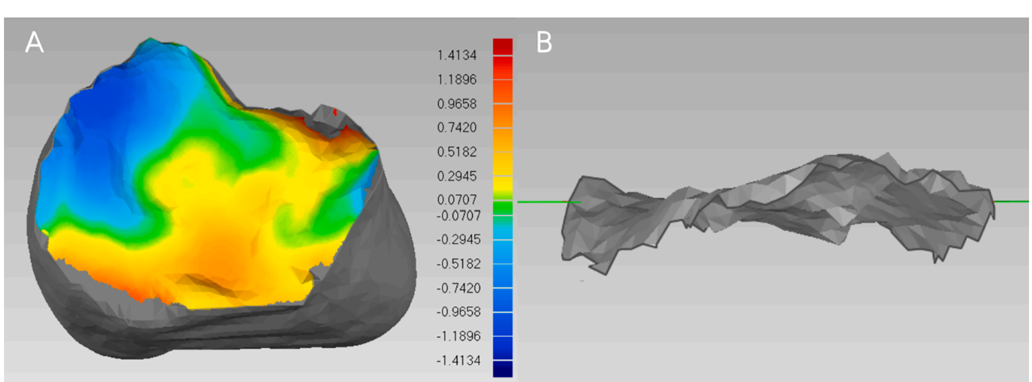

Fig. 3. (A) Geometric deviations between the ideal planned plane and the actual section surface. (B) The relative position of the actual section surface and the ideal planned plane.

Table 1
Demographics, clinical data of patients and accuracy measurements (*N* = 13 teeth).

No. of patient	Gender	Age (years)	Tooth	Impacted type	Pell & Gregory classification	RMS (mm)	Max deviation (mm)	Deviation range (%)			Most convex position	Most concave position
								<1mm	1mm-2mm	2mm-3mm		
1	F	30	R	Horizontal	B	0.43	0.95/−1.21	73.03	19.55	7.42	BM	BD
2	F	28	R	Horizontal	C	0.51	1.25/−2.03	71.71	22.42	5.52	BM	BD
3	F	32	R	Mesial	A	0.85	2.99/−2.35	77.83	12.60	8.93	LD	LD
4	F	32	L	Mesial	A	0.80	1.91/−1.85	86.12	11.06	0.22	BD	BM
5	F	30	R	Lingual	B	0.40	1.02/−1.25	66.46	29.40	3.93	LM	BM
6	F	24	L	Horizontal	B	0.65	1.76/−1.36	69.57	26.85	3.58	LM	BD
			R	Mesial	C	0.62	0.73/−2.38	76.19	17.20	5.56	LM	LD
7	F	27	L	Mesial	A	0.48	0.96/−1.35	64.47	32.46	3.07	BM	BD
8	M	30	R	Horizontal	A	0.77	2.00/−2.27	70.39	23.54	5.97	BD	LD
9	M	28	R	Vertical	C	0.84	0.25/−2.52	72.75	22.75	3.55	BM	BM
10	M	28	L	Mesial	B	0.87	0.69/−2.98	70.53	26.14	2.28	BM	LM
11	M	29	R	Horizontal	A	1.11	2.85/−0.86	65.68	31.08	3.24	BM	BD
12	M	26	L	Mesial	A	0.60	1.52/−1.85	70.82	23.38	5.46	LM	BD
Mean ± SD		28.67 ±2.35				0.69 ±0.21	1.45±0.83/ −1.87±0.63	71.97 ±5.72	22.96 ±6.57	4.52 ±2.28		

Abbreviations: RMS, root mean square; F, female; M, male; R, right; L, left; BM, buccal mesial; BD, buccal distal; LM, lingual mesial; LD, lingual distal.
Thirteen teeth were treated in twelve patients.
No. of patients was coded according to the sequence of surgery.

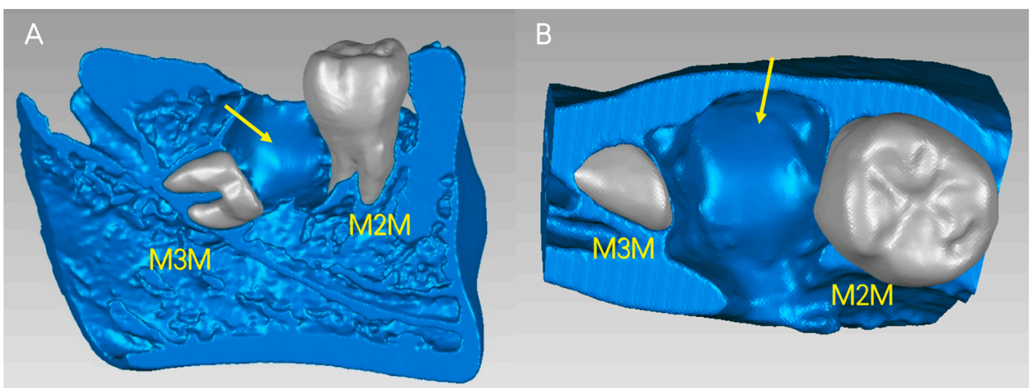

Fig. 4. The grinding of the drill on the surface of the tooth extraction socket did not cause any visible dent formation. (A) The lingual bone plate of the extraction socket. (B) The bottom of the extraction socket.

impaired. The deep narrow space is poorly suited for surgery and may also hamper registration by the DNS equipment. This study is the first verification of the accuracy of retromolar DNS-assisted M3M coronectomy procedures performed via a buccal approach. When performing traditional third molar extraction, verification of the accuracy of the surgical procedure is challenging due to the destruction of the tooth sectioning plane. The current study aimed to evaluate the accuracy of coronectomy by assessing the remaining root surface. This assessment may serve as a significant reference for extraction procedures assisted by navigation technology and other types of retromolar surgery, such as external oblique block bone resection.

Another factor that potentially affects the procedural accuracy of tooth extraction is the fact that current navigation systems are not equipped to support irregular 3D boundaries when performing tooth sectioning. Implant navigation systems provide information about the depth and orientation of the instrument, relying on virtual cylindrical implants that have been specifically constructed. This technology enhances the precision of implantation procedures by minimizing both linear and angular variations across different stages [31,32]. When employing navigation techniques for extraction procedures, it is important to note that the guiding groove may not provide an accurate representation of the 3D boundary of the tooth sectioning surface due to the irregularities present in the tooth boundaries. Consequently, this irregularity increases the risk of damage to surrounding anatomical structures, which may result in complications such as bleeding, nerve damage, or other adverse outcomes. In this study, the site that displayed the most significant deviation from the ideal plane was located in the mesial region of the root, which was proximal to the base of the extraction socket. This deviation was attributed to inadequate removal of tooth tissue, consistent with previous findings that have reported the presence of enamel residue after free-hand coronectomy procedures [29]. Enamel removal from this region almost inevitably necessitates the removal of additional buccal bone, resulting in further trauma. In the future, it is crucial to further improve the ability of navigation technology to match irregular 3D boundaries during surgical procedures, as this would greatly reduce the potential trauma when used for coronectomy and tooth extraction procedures. In addition, there are also areas worth improving in terms of equipment and design. At present, the reference devices and handpiece locator used for navigation are relatively cumbersome, resulting in some difficulties in operation. Another problem is that the navigation design and registration process before surgery is somewhat time-consuming. During the surgery, the handpiece locator and the reference device might block each other's signals, and sometimes it is necessary to stop the surgery and adjust the position of the equipment placement, thus prolonging the procedure. At present, the operation time for navigation-assisted coronectomy appears to be slightly longer than that of traditional coronectomy. One of the reasons for this was that more time was spent defining the remaining roots to achieve higher accuracy.

Although these results demonstrate potential, it is important to acknowledge the limitations of this pilot study, which include a small sample size and the absence of a control group.

5. Conclusions

In conclusion, this study represents the first investigation into the precision of DNS-based methodologies in the context of retromolar surgical interventions conducted through a buccal approach. The data presented here offer the first confirmation of the effectiveness of this strategy in improving the precision of coronectomy procedures and minimizing potential trauma. This study also provides valuable insights for the wider implementation of this technology in the context of other intricate tooth extraction procedures.

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CRediT authorship contribution statement

Hao-Xiang Zhang: Data curation, Formal analysis, Software, Validation, Writing – original draft. **Zi-Yu Yan:** Data curation, Formal analysis, Methodology, Validation, Writing – review & editing. **Nian-Hui Cui:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Feng Sun:** Conceptualization, Methodology, Writing – review & editing. **Bin-Zhang Wu:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare there is no conflict of interests.

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