Clinical Oral Investigations (2023) 27:1499–1507
https://doi.org/10.1007/s00784-022-04769-3

RESEARCH

3D-printed titanium surgical guides for extraction of horizontally impacted lower third molars

Wei Qi[1,2] · Jing Qian[3,2] · Wei Zhou[1,2] · Jiannan Li[1,2] · Bochun Mao[4,2] · Aonan Wen[2] · Yijiao Zhao[2] · Jie Pan[1,2] · Yong Wang[2]

Received: 7 August 2022 / Accepted: 3 November 2022 / Published online: 14 November 2022

Abstract

Objectives This prospective study introduced a digitally designed sectioning guide and evaluated its feasibility for the extraction of horizontally impacted lower third molars.

Materials and methods This study included 38 horizontally impacted lower third molars, randomly divided into experimental and control groups. The teeth were extracted using a 3D-printed titanium surgical guide in the experimental group; free-hand extractions were performed in the control group. The surgical duration, tooth sectioning duration, cortical bone perforation, and postoperative complications, including pain, swelling, trismus, dry socket, infection, and hemorrhage, were evaluated.

Results Although not statistically significant, guided surgery tended to reduce the number of tooth sectioning steps compared to free-hand extractions. There were no cases of cortical bone perforation in the experimental group. Although the surgical duration was greater in the experimental group ($p < 0.05$), there were no differences in postoperative pain, swelling, and trismus. There were no cases of postoperative infection and hemorrhage in either group.

Conclusions 3D-printed titanium surgical guides had superior accuracy and safety compared to free-hand surgery. Further studies with larger sample sizes are required to verify these findings.

Clinical relevance The template improved the safety of tooth sectioning during impacted lower third molar surgery and resulted in a more predictable extraction. The narrow sectioning groove could fit comfortably with hypertrophic soft tissues in the posterior mandible.

Keywords Guided surgery · Impacted lower third molar · Horizontal · Postoperative complication

Introduction

With the development of dental turbine systems, tooth sectioning has become common during extraction of horizontally impacted mandibular third molars (LM3s) [1, 2]. Direct visualization of the surgical field is limited by the small intermaxillary distance and the position of teeth in the posterior mandible, which may cause errors in the site and angulation of tooth sectioning. This increases the surgical duration and risk of postoperative complications, including pain, swelling, and trismus, especially in deeply impacted teeth. Therefore, improvements in the accuracy of tooth sectioning are urgently required.

Computer-planned three-dimensionally printed (3D-printed) surgical templates are widely used in various sub-specialties of stomatology, particularly in dental implantology [3–8]. Research has indicated satisfactory accuracy of guided implant surgery with acceptable deviations in angulation and depth [3, 9–12]. However, few studies have reported application of 3D-printed guided surgery in impacted tooth extraction [8, 13, 14], especially in the posterior mandible. Moreover, none of the templates could control the site and angulation of tooth sectioning. In the present study, we introduce a novel computer-planned 3D-printed surgical template and evaluate its feasibility and efficiency in horizontally impacted LM3 extraction. In contrast with previous studies, the template could not only ascertain the angle for crown and root sectioning, but also restrict the working boundaries of the drill. Furthermore, anatomical and visual limitations

✉ Jie Pan
panjie72@sina.com

✉ Yong Wang
kqcadc@bjmu.edu.cn

Extended author information available on the last page of the article

could also be partially overcome using the template. The results indicated that guided extractions had better safety and predictability than free-hand extractions of LM3s.

Materials and methods

This prospective study was performed in accordance with the Declaration of Helsinki after approval by the Ethical Review Board of Peking University School and Hospital. Informed consent was obtained from all participants.

Patients and groups

The study included patients who presented to the General Department of Peking University School of Stomatology. The inclusion criteria were as follows: healthy patients without systemic diseases; horizontally impacted teeth; Pell and Gregory class II/III and B/C; no dental caries or metal/ceramic restorations in the second molar. The patients were randomly divided into experimental (teeth extracted using a 3D-printed surgical template) and control (free-hand tooth extraction) groups. All the teeth were extracted by a single experienced surgeon using a previously reported tooth-sectioning protocol [15].

Template design and fabrication

Preoperative cone-beam computed tomography (CBCT) of the mandible and dentition was performed and recorded in Digital Imaging and Communications (DICOM) format. Digital mandible data was extracted using Mimics 21.0 software (Materialise NV, Leuven, Belgium). Plaster mandibular full arch models were formed and scanned using 3D laser scanning equipment. Finally, both the digital mandible and scanning model were input into the Geomagic studio software (3D Systems, Rock Hill, SC, USA) for template fabrication (Fig. 1).

Herein, two templates were printed, one for crown and root sectioning each. The 1-mm sectioning template was composed of a retainer, connector, and sectioning groove. The retainer covered the area above the height of contour (HC) between the second premolar and the second molar. Cylinder connectors with 1 mm diameter connected the

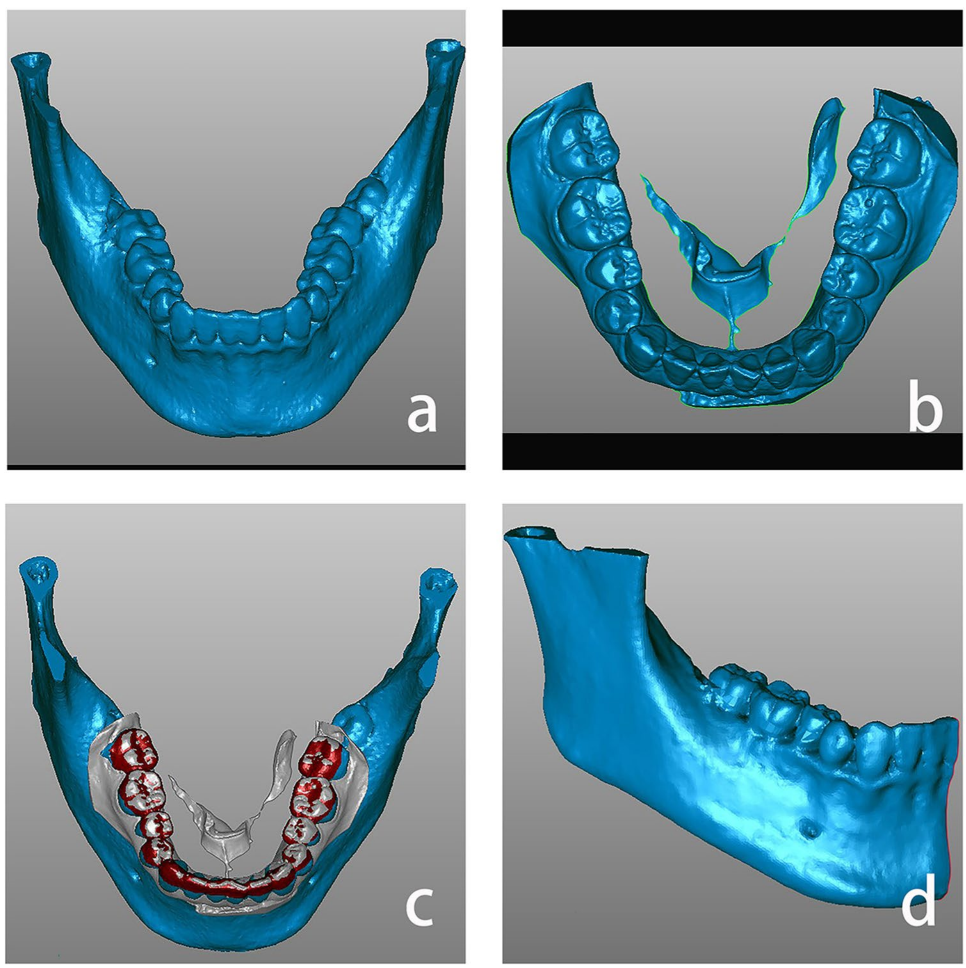

Fig. 1 Jaw-dentition fusion model with high-accuracy dentition data. **a** 3D models of the mandible were exported from preoperative CBCTs using mimics 21.0 software. **b** Data for the entire dentition were obtained by scanning the dentition models. **c** The STL files were aligned with the dental scan in Geomagic Wrap 2021 for optimal fit based on the clinical crown. **d** A jaw-dentition fusion model with high-accuracy dentition data was established by combining the clinical crowns from the dental scan and the digital mandible

retainer and the groove. The U-shaped sectioning groove was 4 mm high and 1.8 mm wide, and included crown and root sectioning grooves. The main function of the groove was to determine the surgical perspective and control the angulation of crown or root sectioning. In case of limited intermaxillary distance or obstruction by the pterygomandibular fold, the crown sectioning groove could be inclined slightly buccally. The root sectioning plane was transverse to the distal enamel-cementum junction (ECJ) of the crown and the root bifurcation (multiple roots) or the middle part of the roots (fused root), whereas the crown sectioning plane was transverse to the distal HC and the mesial ECJ of the crown [15]. Both of the sectioning planes were vertical to the sagittal plane of the LM3. In case of lingual perforation, the lingual margin of the groove was designed to restrict the fissure bur to 1 mm from the lingual margin of the tooth. The inferior surface of the groove was designed to fit with the adjacent hard tissue after Boolean calculations using the Geomagic studio software. Thus, stability of the surgical guide could be ensured through the retainer and the groove (Fig. 2).

Surgical protocol

After local anesthesia with 4% articaine, a modified triangular flap was elevated from the mesiobuccal margin of the second molar to the anterior edge of mandibular ramus. Bone was partially removed to expose the crown of the impacted teeth. In the experimental group, the sectioning template was used to check for prying and as a soft tissue barrier. Guided crown and root sectioning was subsequently completed using the corresponding templates with a high-speed handpiece. In the control group, free-hand extractions were performed. Teeth were sectioned and removed using a previously reported protocol [15]. Finally, the wound was irrigated with 0.9% saline and closed with two nylon sutures (Fig. 3).

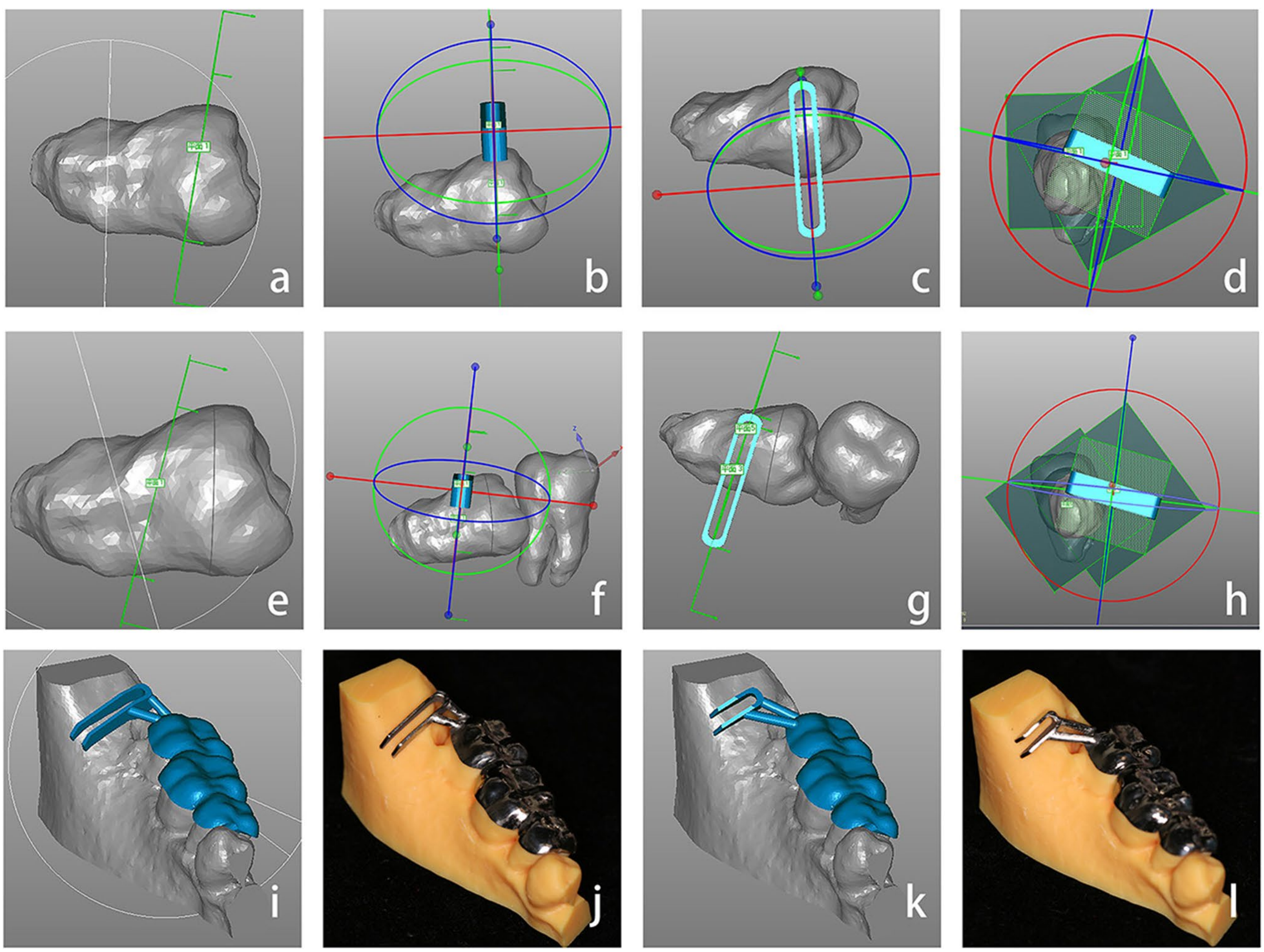

Fig. 2 Template fabrication. **a**, **e** Establishing the crown or tooth sectioning plane (green line). **b**, **f** Inserting the sleeve to check the inclination angle. **c**, **g** Checking the buccal-lingual position of the sleeve. **d**, **h** Lingual margin of the sleeve should not exceed the lingual edge of the teeth. **i**, **j** Crown sectioning template. **k**, **l** Root sectioning template

Analgesics and antibiotics were prescribed postoperatively; 0.5 g of oral amoxicillin (Zhejiang Jinhua CONBA Bio-pharm. Co., Ltd., Jinhua city, China) was administered thrice a day (once every 8 h) for 2 days and ibuprofen was administered as needed. This protocol of antibiotic administration was based on suggestions from the pharmacist and the Ethical Review Board of Peking University School and Hospital.

Surgical duration

The surgical duration was recorded from the beginning of the incision to wound closure.

Tooth sectioning

The steps of tooth sectioning with the drill were recorded. Each tooth required sectioning at least thrice, including T-shaped crown sectioning (sectioning performed twice) and a groove made in the distal ECJ for root sectioning or for elevator luxation of the root. Total tooth sectioning steps (TTP) and the required additional steps (ATS, ATS = TTS-3) were both recorded for analysis.

Postoperative complications

The preoperative maximal mouth opening (MMO) was measured as the distance between the mesial-incisal corners of the upper and lower central incisors. Facial contours (FC) were determined based on a previous study [16]. All examinations were repeated on the 2nd and 7th postoperative days. Postoperative variations in MMO and FC were recorded as trismus and swelling. Pain was assessed using a 0 to 100 visual analogue scale (VAS) and the amount of ibuprofen consumption.

Lingual and apical bone perforations was checked before wound closure. Postoperative hemorrhage and dry socket were also assessed during the follow-up.

Statistical analysis

The differences in surgical duration, postoperative pain, and TTS were analyzed using Mann–Whitney *U* test. Postoperative complications (trismus and swelling) were compared between the two groups using the *t* test. The remaining complications, including the need for ATS, cortical bone perforations, dry socket, and hemorrhage, were compared using the

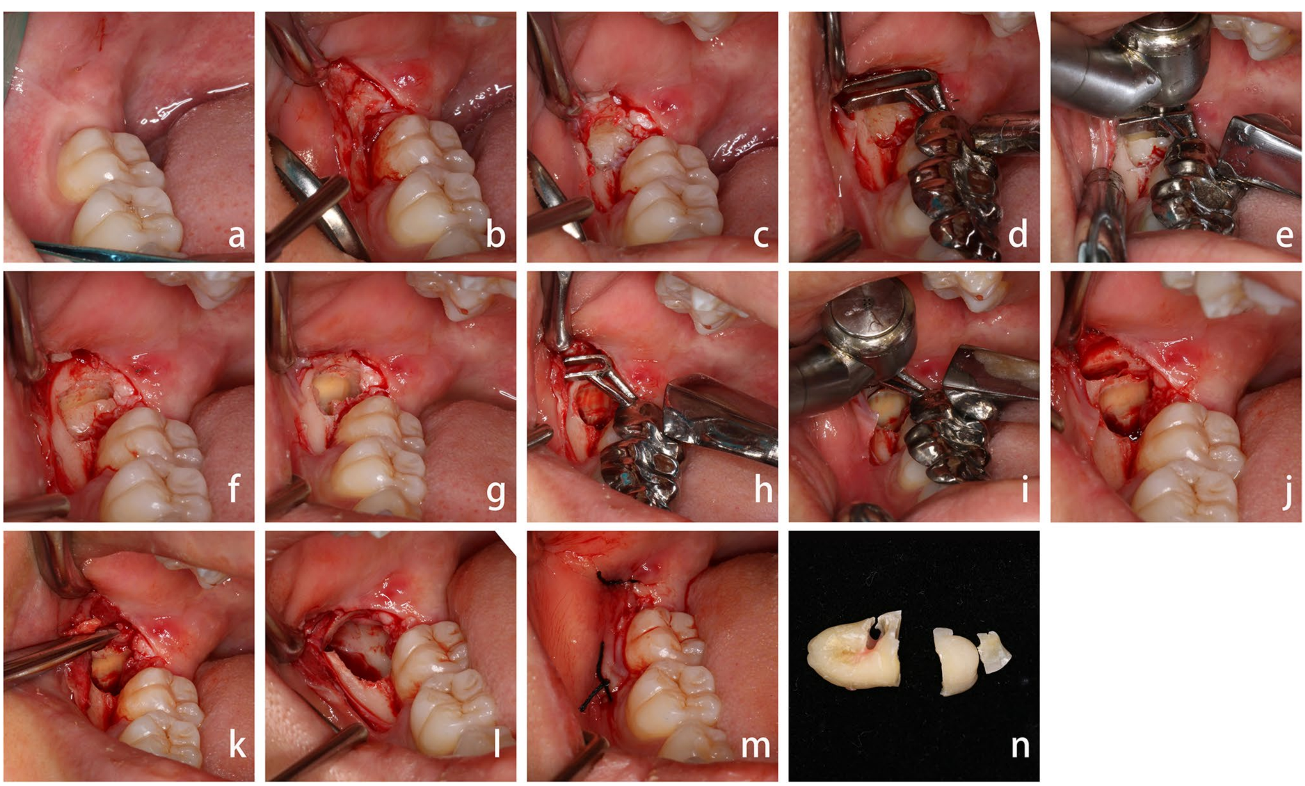

Fig. 3 Protocol for template surgery. **b** Modified triangular flap elevation to expose the teeth. **c** Partial bone removal to expose the crown. **d**, **e** Crown sectioning groove placement and guided crown sectioning. **f**, **g** T-shaped sectioning of the separated crown. **h**, **i** Root sectioning groove allocation and guided root sectioning. **j** Groove prepared by the template. **k** Winter elevator inserted into the groove to extract the root mesially. **l** The socket. **m** Wound closure. **n** The extracted tooth

Chi square test. SPSS Statistics 20.0 (IBM Corp., Armonk, NY, USA) was used for statistical analyses. p-values < 0.05 were considered statistically significant.

Results

This study included 38 teeth from 35 patients. Among them, 15 patients were male and 20 patients were female. Patient details are shown in Table 1. Although the surgical duration was significantly longer in the experimental group, there were no significant differences in postoperative pain, swelling, and trismus. Guided tooth extractions required fewer TTS compared to free-hand extractions; however, the difference was not statistically significant ($p > 0.05$). As the template restricted the cutting range of the drill, there was no cortical bone perforation in the experimental group, but occurred in three teeth in the control group. Dry socket, infection, and hemorrhage did not occur in any patient of either group (Table 1).

Table 1 Study findings

	Control group	Experimental group	p value
Age, y	28.88 ± 2.17 (25–32)	30.1 ± 3.24 (25–40)	0.194
Sex			
Male	11	11	0.703
Female	9	7	
Surgical duration, min	15.1 ± 6.47	29.16 ± 9.97	< 0.001
Swelling, cm			
*P2	1.35 ± 1.14	1.26 ± 1.12	0.44
P7	0.46 ± 0.45	0.43 ± 0.50	0.51
Trismus, mm			
P2	13.94 ± 8.58	13.42 ± 9.50	0.6
P7	7.53 ± 7.01	6.42 ± 6.87	0.86
VAS			
P2	3.1 ± 1.24	3.12 ± 1.06	0.52
P7	1.05 ± 0.85	0.74 ± 0.81	0.55
Ibuprofen consumption*	1.74 ± 1.52	0.89 ± 1.05	0.26
Mesial bone perforation	2	0	–
Lingual bone perforation	1	0	–
TTS*	3.6	3.4	0.201
Patients who required ATS*	8/20	5/18	0.506

Values are means ± standard deviation. Significance level was $p < 0.05$

**P*, postoperative day; *TTS*, total teeth sectioning time; *Ibuprofen consumption*, number of Ibuprofen tablets used; *ATS*, additional teeth sectioning time

Discussion

In the present study, we designed a novel tooth sectioning template for horizontally impacted LM3s without the need for an extended incision. The template replicated the preoperative design with an acceptable postoperative complication rate compared to free-hand tooth sectioning. The template could also be used to correct the osteotomy as it facilitated the location of the teeth.

Bone removal and tooth sectioning are frequently performed in deeply impacted LM3s, classically using high-speed drills [17–27]. Due to the high cutting efficiency, adjacent tissues may get injured when the drills are deeply driven [17, 19, 20]. Yadav et al. reported that tooth sectioning using fissure burs was a major risk factor for intraoperative lingual nerve injury [20]. Hence, many surgeons prefer piezosurgery for osteotomies because of its selective cutting and reduced soft tissue injury [11–25, 27]. Ye et al. and Paolo extracted LM3s by removing the overlying cortical bone block using piezosurgery, and found that this effectively reduced postoperative inferior alveolar nerve dysfunction [21, 27]. Laino et al. extracted deeply impacted LM3s through an extroral approach using piezosurgery, and reported that both the marginal mandibular branch of the facial nerve and the facial artery remained well protected [22]. However, low efficiency of piezosurgery in tooth sectioning may increase the surgical duration [1, 23, 24]. In a recent systematic review, Cicciù et al. reported that there was still a lack of evidence to determine whether piezosurgery significantly reduced postoperative complications compared to burs [1]. Therefore, tooth sectioning using rotary instruments remains a valuable technique for extraction of impacted wisdom teeth [1, 2]. Generally, the multiple roots can be separated either through the pulp floor or through the distal root. However, it is difficult to section the roots of horizontally impacted LM3s through the pulp floor with a high-speed turbine. Therefore, the teeth involved were sectioned based on our previously reported findings [15]. Both the cutting planes inclined mesially rather than vertically, which facilitated drill positioning and compensated for the limited intermaxillary distance.

Guided surgery is widely used in implantology and endodontics to improve treatment accuracy and success rate [6, 9, 10]. It has been reported that computer-aided implant surgery is a reliable technique that results in a mean angle deviation of 3° and a mean linear deviation of 1.2–1.5 mm from the target. Recently, guided extractions have also been performed in cases of complicated impacted teeth. Ahmed et al. in a prospective cohort study reported the use of a digital cutting guide during LM3 extractions [13]. The template was designed to ascertain the osteotomy position and prevent excessive bone removal rather than control the sectioning site and angulation. Besides, the large template size required extensive flap elevation, which could increase postoperative swelling. In contrast, our template was 1 mm thick and was much smaller than previous designs. This allowed passive positioning without the need for an extended flap. The increased surgical duration was mainly due to intraoperative photography and surgeon experience in our research. Because of improved accuracy, the rate of surgical complications, including swelling, trismus, and pain, was comparable to that of the control group. In addition, although guided surgery reduced the TTS, the difference was not statistically significant, which may be because of the limited sample size of this study.

The accuracy of guided surgery was affected by several factors, including material of the sleeve, intraoperative support methods, the clearance between the guiding hole and the drill, and drilling distance below the guiding sleeve [3]. Implant templates are generally fabricated using polylactic acid (PLA) and non-metal sleeve guides have been recommended to reduce lateral drill movements and instrument tolerance. Because of the high revolution speed and cutting efficiency of fissure burs, PLA sleeves could not restrict the cutting angle. Besides, larger templates are required to ensure adequate PLA rigidity. In this case, hypertrophic mucosa adjacent to the pterygomandibular fold could interfere with template placement. Meanwhile, the 1-mm thick titanium groove could be placed passively without the need for a larger flap or compromising template rigidity (Fig. 3). Preoperatively, both the surgeon and the designer should carefully assess the relative positions of impacted LM3s and pterygomandibular folds. Placement difficulties occurred in only one case because the pterygomandibular fold interfered with the placement of the lingually located groove and a larger flap was required.

The support mode was also closed related to the accuracy of the template. Arisan [28] suggested using two or more immobile teeth to support the surgical guide. Surgical guides supported by 3 posterior teeth produce the same accuracy achieved by full arch guides in posterior implant sites [3]. Therefore, we designed a retainer for three posterior teeth. Additionally, the tissue surface of the groove closely contacted the teeth or the cortical bone to achieve two-point retention. Intraoperatively, the tip of the osteotome was pressed on the retainer to stabilize the template (Fig. 3).

The occluso-gingival heights and inner diameters of the guides played an important role in the control of angular deviation. A 9-mm drilling guide allow greater reduction of both left-to-right and front-to-back deviations compared to 6-mm guides [29]. Liang et al. [30] found that dramatically less angular control was achieved using 2–5 mm high sleeves compared to 8–10 mm sleeves. Meanwhile, Park et al. reported no significant differences between 4, 6, and 8 mm occluso-gingival heights [31]. In addition, to ensure smooth gliding of the drill through the guiding sleeve, the inner width of the sleeve should be larger than the outer diameter of the drill. Choi et al. [29] in an in vitro study reported that angular deviations were not significantly different among various diameters (2.3 mm twist drills; inner diameter, 2–5 mm). As the interocclusal distance is limited in the posterior mandible, we used a 3–4-mm high sleeve with 1.7 mm inner width (0.2 mm larger than the fissure bur diameter), which did not interfere with instrument placement and improved the accuracy of tooth sectioning. The rigidity of the sleeve would cause the fissure bur to vibrate if it deviated mesial-distally or lingually and contacted the inner sleeve surface; this would indicate to the surgeon that the cutting angle needs adjustment.

In addition, the sleeve also restricted the cutting range of the drill to a safe zone. The lingual boundary of the groove was 1 mm buccal to the lingual margin of the tooth. In addition, the drill was parallel to the lingual margin of the groove during sectioning. Therefore, the risk of lingual bone perforation was reduced. Furthermore, the cutting depth of the fissure bur was controlled by changing the length of the bur. The working lengths of 20 mm, 25 mm, and 28 mm fissure burs were 10 mm, 15 mm, and 18 mm, respectively. The 4 mm sleeve height ensured that the drill ended 1 mm from the mesial tooth margin. Therefore, there were no cases of apical cortical bone perforation in the experimental group.

Finally, time and cost investment were also important factors to evaluate the cost-effectiveness of titanium surgical guide fabrication. In the present study, most of the templates were designed by the surgeon responsible for tooth extraction. The time durations for data extraction (full arch mandible and LM3s) and template design were 30–40 min and 1–1.5 h (two templates), respectively, with a total time of 1.5–2 h. The time consumed may be reduced when designed by specialized engineers. Furthermore, the cost of the template mainly consisted of preoperative CBCT (320 RMB), plaster model screening (50 RMB), and template printing (320 RMB for each template), with a total of 1010 RMB. Since CBCT is required for the evaluation of deeply impacted LM3s and those adjacent to the inferior alveolar nerve, its cost should not be included in the total cost of titanium template fabrication for complicated LM3s.

Despite high cost of the template, it is still a valuable and cost-effective alternative for complicated LM3s extraction, especially for inexperienced surgeons. Incorrect tooth section could significantly increase the surgical duration and cause accidental perforations of the adjacent tissues, which increases the risk and severity of postoperative complications. There may also be a need for more follow-up visits and adjuvant therapies, which also increases the treatment duration and economic burden. Moreover, the quality of life during the first few postoperative days is also negatively affected due to the complications. Therefore, guided surgery may theoretically reduce the overall time and cost of the procedure by making it more predictable. Although two templates were designed in the present study, a single template may be used based on the surgeon's experience with root or crown sectioning. Furthermore, templates could safely be used to train surgeons in the essentials of tooth sectioning and the surgical technique.

The main limitations of this study were as follows. Since extractions of deeply impacted horizontal LM3s have a high difficulty level, these procedures were performed by experienced surgeons. Therefore, both the superiority and drawbacks of guide extractions may have been underestimated. Future studies of guided surgeries performed by inexperienced surgeons are required to further verify the efficiency and significance of templates.

Conclusions

The digital template with a sectioning sleeve increased the safety of LM3 surgery without the need for a larger flap and resulted in a more predictable surgery. Further multicenter studies with larger sample sizes are needed to verify these findings and improve the template design. Furthermore, special burs with proper lengths are needed to improve the accuracy of the cutting depth.

Author contributions Wei Qi and Jing Qian proposed the template design; Wei Qi, Yijiao Zhao, and Yong Wang accomplished the final template design. Wei Qi, Wei Zhou, Jiannan Li, and Jie Pan were involved in patient follow-up and clinical data collection. Wei Qi, Bochun Mao, and Aonan Wen processed the CBCT data and produced the digital templates. Wei Qi and Jing Qian analyzed the data. Wei Qi wrote the manuscript. Jie Pan and Yong Wang revised the paper.

Funding The research was supported by New Clinical Techniques and Therapies of Peking University School and Hospital of Stomatology (PKUSSNCT-20A08).

Declarations

All the authors have read and understood the publishing policy and have submitted this manuscript in accordance with the policy. We declare that the authors have no competing interests as defined by Springer, or any other interests that might be perceived to influence the results and/or discussion reported in this paper. The corresponding author has read the Springer journal policies on author responsibilities and has submitted this manuscript in accordance with these policies.

Competing interests The authors declare no competing interests.

Ethics approval and consent to participate This prospective study was performed in accordance with the Declaration of Helsinki after approval by the Ethical Review Board of Peking University School and Hospital. Informed consent was obtained from all participants.

Conflict of Interest The authors declare no competing interests.

References

1. Cicciù M, Stacchi C, Fiorillo L, Cervino G, Troiano G, Vercellotti T, Herford AS, Galindo-Moreno P, Di Lenarda R (2021) Piezoelectric bone surgery for impacted lower third molar extraction compared with conventional rotary instruments: a systematic review, meta-analysis, and trial sequential analysis. Int J Oral Maxillofac Surg 50(1):121–131. https://doi.org/10.1016/j.ijom.2020.03.008
2. Magesty RA, Galvão EL, de Castro MC, Dos Santos CRR, Falci SGM (2017) Rotary instrument or piezoelectric for the removal of third molars: a meta-analysis. J Maxillofac Oral Surg 16(1):13–21. https://doi.org/10.1007/s12663-016-0938-y
3. El Kholy K, Lazarin R, Janner SFM, Faerber K, Buser R, Buser D (2019) Influence of surgical guide support and implant site location on accuracy of static Computer-Assisted Implant Surgery. Clin Oral Implants Res 30(11):1067–1075. https://doi.org/10.1111/clr.13520
4. Gao J, Li J, Liu C, Fan L, Yu J, Yu H (2020) A stereolithographic template for computer-assisted teeth preparation in dental esthetic ceramic veneer treatment. J Esthet Restor Dent 32(8):763–769. https://doi.org/10.1111/jerd.12644
5. Connert T, Zehnder MS, Weiger R, Kühl S, Krastl G (2017) Microguided endodontics: accuracy of a miniaturized technique for apically extended access cavity preparation in anterior teeth. J Endod 43(5):787–790. https://doi.org/10.1016/j.joen
6. Moreno-Rabié C, Torres A, Lambrechts P, Jacobs R (2020) Clinical applications, accuracy and limitations of guided endodontics: a systematic review. Int Endod J 53(2):214–231. https://doi.org/10.1111/iej.13216
7. Xingzhou Q, Wang Z, Ong HS, Chenping Z, Abdelrehem A (2020) Accuracy of computer-aided design/computer-aided manufacturing surgical template for guidance of dental implant distraction in mandibular reconstruction with free fibula flaps. J Craniofac Surg 31(2):355–359. https://doi.org/10.1097/SCS.0000000000006112
8. Verweij JP, Jongkees FA, Anssari Moin D, Wismeijer D, van Merkesteyn JPR (2017) Autotransplantation of teeth using computer-aided rapid prototyping of a three-dimensional replica of the donor tooth: a systematic literature review. Int J Oral Maxillofac Surg 46(11):1466–1474. https://doi.org/10.1016/j.ijom.2017.04.008
9. Smitkarn P, Subbalekha K, Mattheos N, Pimkhaokham A (2019) The accuracy of single-tooth implants placed using fully digital-guided surgery and freehand implant surgery. J Clin Periodontol 46(9):949–957. https://doi.org/10.1111/jcpe.13160
10. Tahmaseb A, Wu V, Wismeijer D, Coucke W, Evans C (2018) The accuracy of static computer-aided implant surgery: a systematic review and meta-analysis. Clin Oral Implants Res 29(Suppl 16):416–435. https://doi.org/10.1111/clr.13346
11. Schelbert T, Gander T, Blumer M, Jung R, Rücker M, Rostetter C (2019) Accuracy of computer-guided template-based implant surgery: a computed tomography-based clinical follow-up study. Implant Dent 28(6):556–563. https://doi.org/10.1097/ID.0000000000000936
12. Park JY, Song YW, Park SH, Kim JH, Park JM, Lee JS (2020) Clinical factors influencing implant positioning by guided surgery using a nonmetal sleeve template in the partially edentulous ridge: multiple regression analysis of a prospective cohort. Clin Oral Implants Res 31(12):1187–1198. https://doi.org/10.1111/clr.13664
13. Ahmed M, Salah MK, Khairy N (2018) Computer-aided design/computer-aided manufacturing cutting guides for odontectomy of deeply impacted mandibular third molars. Maced J Med Sci 6(12):2395–2401. https://doi.org/10.3889/oamjms.2018.371
14. Wang J, Cui NH, Guo YJ, Zhang W (2017) Navigation-guided extraction of impacted supernumerary teeth: a case report. J Oral Maxillofac Surg 75(6):1136.e1-1136.e5. https://doi.org/10.1016/j.joms.2017.02.001
15. Qi W, Lei J, Liu YN, Li JN, Pan J, Yu GY (2019) Evaluating the risk of post-extraction inferior alveolar nerve injury through the relative position of the lower third molar root and inferior alveolar

canal. Int J Oral Maxillofac Surg 48(12):1577–1583. https://doi.org/10.1016/j.ijom.2019.07.008
16. Sandhu A, Sandhu S, Kaur T (2010) Comparison of two different flap designs in the surgical removal of bilateral impacted mandibular third molars. Int J Oral Maxillofac Surg 39(11):1091–1096. https://doi.org/10.1016/j.ijom.2010.07.003
17. Szalma J, Lovász BV, Lempel E, Maróti P (2019) Three-dimensionally printed individual drill sleeve for depth-controlled sections in third molar surgery. J Oral Maxillofac Surg 77(4):704.e1-704.e7. https://doi.org/10.1016/j.joms.2018.11.028
18. Jain N, Thomas S, Prabhu S, Jain S, Pathak AD, Pillai A, Satpathy M (2016) Influence of tooth sectioning technique and various risk factors in reducing the IAN injury following surgical removal of an impacted mandibular third molar. Oral Maxillofac Surg 20(2):149–156. https://doi.org/10.1007/s10006-015-0540-3
19. Mavrodi A, Ohanyan A, Kechagias N, Tsekos A, Vahtsevanos K (2015) Influence of two different surgical techniques on the difficulty of impacted lower third molar extraction and their post-operative complications. Med Oral Patol Oral Cir Bucal 20(5):e640–e644. https://doi.org/10.4317/medoral.20605
20. Yadav S, Verma A, Sachdeva A (2014) Assessment of lingual nerve injury using different surgical variables for mandibular third molar surgery: a clinical study. Int J Oral Maxillofac Surg 43(7):889–893. https://doi.org/10.1016/j.ijom.2014.01.013
21. Scolozzi P (2022) Buccal corticotomy using piezosurgery as a surgical approach for removal of deeply impacted mandibular teeth: an alternative procedure to avoid pitfalls associated with the conventional technique. J Stomatol Oral Maxillofac Surg 123(2):142–146. https://doi.org/10.1016/j.jormas.2021.04.012
22. Laino L, Mariani P, Laino G, Cervino G, Cicciù M (2021) Impacted lower third molar under inferior alveolar canal: technical strategy for minimally invasive extraoral surgical approach. J Craniofac Surg 32(5):1890–1893. https://doi.org/10.1097/SCS.0000000000007457
23. Gulnahar Y, Alpan AL (2021) Comparison of postoperative morbidity between piezoelectric surgery and conventional rotary instruments in mandibular third molar surgery: a split-mouth clinical study. Med Oral Patol Oral Cir Bucal 26(3):e269–e275. https://doi.org/10.4317/medoral.24085
24. Silva LD, Reis EN, Bonardi JP, Lima VN, Aranega AM, Ponzoni D (2020) Influence of surgical ultrasound used in the detachment of flaps, osteotomy and odontosection in lower third molar surgeries. A prospective, randomized, and "split-mouth" clinical study. Med Oral Patol Oral Cir Bucal. 25(4):e461–e467. https://doi.org/10.4317/medoral.23447
25. de Freitas Silva L, de Carvalho Ribeiro, Reis EN, Oliveira Souza BC, Egas LS, Aranega AM, Ponzoni D (2019) Alveolar repair after the use of piezosurgery in the removal of lower third molars: a prospective clinical, randomised, double-blind, split-mouth study. Br J Oral Maxillofac Surg 57(10):1068–1073. https://doi.org/10.1016/j.bjoms.2019.09.017
26. Troiano G, Laino L, Cicciù M, Cervino G, Fiorillo L, D'amico C, Zhurakivska K, Lo Muzio L (2018) Comparison of two routes of administration of dexamethasone to reduce the postoperative sequelae after third molar surgery: a systematic review and meta-analysis. Open Dent J 12:181–188. https://doi.org/10.2174/1874210601812010181 (eCollection 2018)
27. Ye ZX, Yang C (2017) Mesiolingual root rotation for horizontal mandibular third molar extraction: position classification and surgical simulation. Sci Rep 7(1):14405. https://doi.org/10.1038/s41598-017-14914-8
28. Arisan V, Karabuda ZC, Ozdemir T (2010) Accuracy of two stereolithographic guide systems for computer-aided implant placement: a computed tomography-based clinical comparative study. J Periodontol 81(1):43–51. https://doi.org/10.1902/jop.2009.090348
29. Choi M, Romberg E, Driscoll CF (2004) Effects of varied dimensions of surgical guides on implant angulations. J Prosthet Dent 92(5):463–469. https://doi.org/10.1016/j.prosdent.2004.08.010
30. Liang Y, YYuan S, Huan J, Zhang Y, Fang C, Li J (2019) In vitro experimental study of the effect of adjusting the guide sleeve height and using a visual direction-indicating guide on implantation accuracy. J Oral Maxillofac Surg 77(11):2259–2268. https://doi.org/10.1016/j.joms.2019.05.017
31. Park C, Raigrodski AJ, Rosen J, Spiekerman C, London RM (2009) Accuracy of implant placement using precision surgical guides with varying occlusogingival heights: an in vitro study. J Prosthet Dent 101(6):372–381. https://doi.org/10.1016/S0022-3913(09)60080-9

Authors and Affiliations

Wei Qi[1,2] · Jing Qian[3,2] · Wei Zhou[1,2] · Jiannan Li[1,2] · Bochun Mao[4,2] · Aonan Wen[2] · Yijiao Zhao[2] · Jie Pan[1,2] · Yong Wang[2]

[1] Department of General Dentistry, Peking University School and Hospital of Stomatology & National Center of Stomatology & National Clinical Research Center for Oral Diseases & National Engineering Laboratory for Digital and Material Technology of Stomatology & Beijing Key Laboratory of Digital Stomatology & Research Center of Engineering and Technology for Computerized Dentistry Ministry of Health & NMPA Key Laboratory for Dental Materials, No. 22, Zhongguancun South Avenue, Haidian District, Beijing 100081, People's Republic of China

[2] Peking University School and Hospital of Stomatology & National Center of Stomatology & National Clinical Research Center for Oral Diseases & National Engineering Laboratory for Digital and Material Technology of Stomatology & Beijing Key Laboratory of Digital Stomatology & Research Center of Engineering and Technology for Computerized Dentistry Ministry of Health & NMPA Key Laboratory for Dental Materials, No. 22, Zhongguancun South Avenue, Haidian District, Beijing 100081, People's Republic of China

[3] Fifth Division of Peking University School and Hospital of Stomatology & National Center of Stomatology & National Clinical Research Center for Oral Diseases & National Engineering Laboratory for Digital and Material Technology of Stomatology & Beijing Key Laboratory of Digital Stomatology & Research Center of Engineering and Technology for Computerized Dentistry Ministry of Health & NMPA Key Laboratory for Dental Materials, No. 22, Zhongguancun South Avenue, Haidian District, Beijing 100081, People's Republic of China

[4] Department of Orthodontics, Peking University School and Hospital of Stomatology & National Center of Stomatology & National Clinical Research Center for Oral Diseases & National Engineering Laboratory for Digital and Material Technology of Stomatology & Beijing Key Laboratory of Digital Stomatology & Research Center of Engineering and Technology for Computerized Dentistry Ministry of Health & NMPA Key Laboratory for Dental Materials, No. 22, Zhongguancun South Avenue, Haidian District, Beijing 100081, People's Republic of China