You *et al. BioMedical Engineering OnLine* (2025) 24:1
https://doi.org/10.1186/s12938-025-01329-0

BioMedical Engineering OnLine

RESEARCH

Open Access

Accuracy evaluation and clinical realization of digital interproximal enamel reduction for orthodontics: a case study

Jia You[1,2†], Xiangyu Zhou[1,2†], Xiaofan Xia[3], Jianxing Zhang[4*] and Yunfeng Liu[1,2*]

†Jia You and Xiangyu Zhou have contributed equally to this work.

*Correspondence: zjxcym@126.com; liuyf76@126.com

[1] College of Mechanical Engineering, Zhejiang University of Technology, Hangzhou 310023, China
[2] Key Laboratory of Special Purpose Equipment and Advanced Processing Technology, Ministry of Education and Zhejiang Province, Zhejiang University of Technology, Hangzhou 310023, China
[3] Hangzhou 6D Dental Tech Co, Ltd., Hangzhou 310023, China
[4] Department of Stomatology, Zhejiang Hospital, Hangzhou 310013, China

Abstract

Objective: This study presents a novel digital interproximal enamel reduction (IER) clinical procedure, aiming to improve the effectiveness of IER processes in orthodontic treatment.

Methods: A malocclusion case of skeletal-class I and angle-class I was selected for the experimental investigation. A three-dimensional (3D) model of the dentition was constructed using scanning data from a plaster model. The IER volume was measured by the overlay area of two neighboring crowns on the arranged virtual teeth. For the upper dentition, a guide plate was innovatively designed based on the original surface of the dentition and the calculated IER volume. The guide plate was fabricated using stereolithography 3D printing (SLA), and was successfully employed during the IER operation. For the lower dentition, the IER procedure was performed using the free-hand method, guided by the predesigned IER volume. Preoperative and postoperative 3D models of the dentition were compared to assess the accuracy of both IER methods.

Results: The standard deviation of upper dentition IER with guide plate was calculated as 0.13 mm, while that of lower dentition IER by freehand was 0.24 mm.

Conclusion: Through the integration of laser scanning, 3D reconstruction, virtual arrangement, guide plate design, and 3D printing, this study not only explores a novel digital IER method, but also demonstrates its clinical applicability. The findings provide compelling evidence of the method's superior accuracy in clinical practice, offering a new approach for high-precision IER operations in orthodontic treatment.

Keywords: Digital interproximal enamel reduction, IER guide plate, Orthodontics, Clinical experiment

Introduction

The common symptom of malocclusion is clearly attributed to crowded dentition, with the main reason being the non-coordination among the patient's teeth and bone mass. Orthodontic treatment provides the conditions for dentition alignment by reducing teeth or increasing bone mass [1]. For patients with mild crowding, non-extraction treatment is often adopted, and interproximal enamel reduction is one of the prominent orthodontic methods to adjust the relationship of tooth and bone mass. The aim of interproximal enamel reduction (IER) or enamel reproximation at the adjacent surface is to reduce the crown volume on the expected aligned teeth. The adjacent parts of the two crowns are slightly grinded to lose the overlay area. A small volume of enamel on the tooth surface is removed to obtain the gap between the two teeth, which reduces the width of teeth and allows the alignment of teeth [2]. IER is an important treatment for patients with mild crowding and inconsistent Bolton index between the upper and lower dentition. Both orthodontic treatments with fixed braces or invisible removable aligners can be implemented based on the dentition with reduced volume, so that those patients with crowded dentition caused by slightly greater tooth mass for the given bone mass can obtain additional tooth space and the original crowding dentition can be neatly arranged.

Recently, digital technology has been widely used in the medical field, such as digital dental implant navigation [3], invisible aligner technique [4], stress analysis of implant [5, 6], and computer-aided personalized tooth correction technology based on biomechanics [7, 8]. In the process of constructing an invisible orthodontic scheme without brackets, the final position of tooth arrangement can be virtualized on the three-dimensional dentition models, the width ratio of upper and lower dentition can be calculated, and the occlusion of dentition after orthodontic treatment can be simulated. Subsequently, the required gap can be determined to align the dentition and coordinate the width ratio between the upper and lower dentition, which has become a common step in invisible orthodontic scheme design. On the other hand, since the force exerted by the invisible appliance on the teeth comes from the thermoplastic polymer elastic resin film, it is necessary for the appliance to contact with the tooth surface to drive the tooth movement. Therefore, in the invisible aligner treatment of 'marginal cases', conservative treatment with non-tooth-extraction is preferred, which highlights the significance of the interproximal enamel reduction technology in invisible aligner treatment.

Some researchers have recently prepared the IER plan by digital orthodontic software, then the accuracy was calculated by comparing the amount of implemented IER with that of the initial plan. The result showed that the amount of implemented IER was significantly less than expected [9, 10]. According to the digital plan, clinicians usually use a tooth gap caliper for measurement while grinding. However, due to the measuring process being completely reliant on the dentist's experience, the errors caused by difference in tightness can be obvious. In addition, because the teeth are suspended in the alveolar fossa by the periodontal ligament, each tooth has a large physiological mobility, which greatly reduces the reliability of measuring the deglazing thickness by caliper. On the other hand, for an isolated tooth from the dentition that does not contact with the adjacent crown, the gap measurement caliper cannot be used, and the grinding area cannot be accurately positioned. Clinicians can only select the grinding position and control the grinding depth through subjective judgment, hence the accuracy cannot be quantitatively controlled. However, if the dental arch is expanded firstly and IER is conducted after the teeth have been aligned on the expended arch, the gaps between crowns are needed to be closed. This process would lead to overly extended treatment time, and a large number of reciprocating tooth motion on buccal–lingual direction would also be acquired, which may cause iatrogenic periodontal tissue damage. When carrying out IER manually by free-hand operation, if the crown volume is grinded too much, excessive gap would remain after the treatment, which would affect the patient's esthetics, and easily lead to food incarceration and secondary caries. On the other hand, if the thickness of IER is insufficient, the crowded teeth will collide in the rotation process of correction alignment, which may cause aligner derailment and the necessity to redesign the braces, resulting in great economic and time loss. In clinical practice, a wrong tooth may even be ground due to the dentist's mistake, which could result in morphological damage in the wrong grinded tooth, and even permanent iatrogenic injury, whereas the right tooth is not grinded.

In order to achieve precise IER operation before orthodontic treatment, some digital techniques are demonstrated in the study to conduct tooth arrangement based on the three-dimensional dentition model. Then, an overlap with the adjacent tooth is obtained on the aligned target dentition by software, and used to determine the IER volume. A customized template is designed on the dentition using the IER plan and fabricated by 3D printing, so that the dentist can achieve precise IER operation.

Results

Clinical effect of IER

The oral dentition of the patient was scanned to obtain the clinical data of oral cavity from the patient after the IER process, and the comparison of the patient before and after IER was obtained. The intraoral orthotopic photograph before and after IER is shown in Fig. 1.

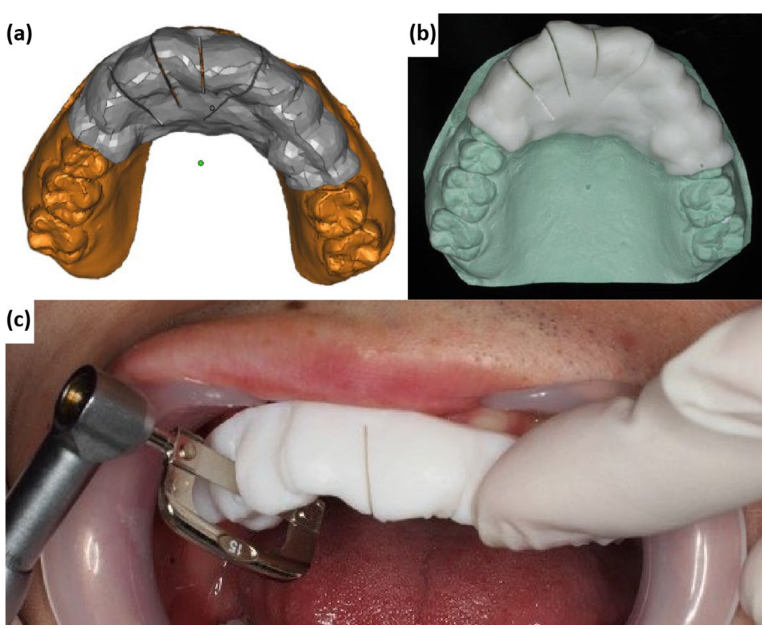

Fig. 1 IER guide template design, fabrication and clinical application: **a** digital 3D model, **b** 3D printed guide template, **c** IER with guide template

Fig. 2 Intraoral orthotopic map: **a** before IER, **b** after IER

Table 1 Error analysis of IER

	Maxilla with guide template				Mandibular without guide template			
Position	1	2	3	4	5	6	7	8
Error (mm)	0.15	0.12	0.11	0.14	0.19	0.27	0.25	0.25
Mean (SD)	0.13 (0.02)				0.24 (0.03)			

Error analysis of IER

According to the IER scheme, the IER area was subtracted from the upper dentition of the patient to construct the theoretical IER digital model. Then, the theoretical IER model and the actual IER model were imported into Geomagic Studio, and the two models were matched by the fitting tool. To reduce the fitting error, the teeth without IER were removed, and only a few teeth were retained as fitting reference, are shown in Fig. 2. The upper dentition IER area of this patient was mainly concentrated in the anterior tooth area. The area that used the guide plate in the upper dentition IER is light blue. Without using the guide template in the lower dentition, the IER area was deeper blue. Deep color represents a large deviation, and the error of using the IER guide template was less than the traditional IER operation.

The measurements before and after IER with guide template in the upper dentition are shown in Fig. 2a, and the measurements before and after IER without guide template in the lower dentition are shown in Fig. 2b. The maximum deviation of IER with guide template in the upper dentition was 0.15 mm, and the maximum deviation of IER in the lower dentition was 0.27 mm under the condition of without using guide template, as shown in Table 1.

The results of IER and deviation analysis of the patient indicated that the accuracy of IER was improved when the IER guide template was used in the upper dentition.

The standard deviation of IER with the guide template was 0.13 mm, while that of the free-hand method in the lower dentition was 0.24 mm, as shown in Table 1.

Discussion

In general, the thickness of a single tooth unilateral IER needs to be in the range of 0.15–0.25 mm, while using IER guide template could improve the accuracy to 0.11–0.15 mm, which has great clinical significance. Hariharan et al. enrolled 75 subjects to evaluate the correspondence between the interproximal reduction performed clinically and that programmed in ClinCheck®. In their research, the mean programmed IER for the maxillary teeth was 0.28 ± 0.16 mm versus the mean implemented IER of 0.15 ± 0.15 mm [10]. In comparison, the template-guided IER in our research had a significant precision advantage over the free-hand IER.

Historically, Ballard [12] proposed the adjustment of tooth size via the crown slice cutting technology (IER) to obtain a coordinated dentition. Since then, IER technology has been developed considerably and applied widely in orthodontics. Begg [13] put forward an important theory of tooth attrition, in which the malposed teeth have no adjacent tooth attrition and could be compensated by enamel reduction. Furthermore, they pointed out that reducing the width of incisors and canines better satisfied the basic biological requirements than orthodontic extraction. Stroud et al. [14] carried out research on the mesial and distal enamel thickness of permanent molars and premolars. The results showed that the enamel of each tooth could be reduced within 50%, which could provide 9.8 mm additional space for orthodontics. Zachrisson Björn [15] proposed that enamel reduction on the tooth surface could improve the esthetics of the front teeth and reduce the risk of gingival recession after the orthodontic surgery. Livas et al. [16] discussed the evolution process and development trend of interproximal enamel reduction technology, and concluded that IER had become an effective treatment for orthodontists. Relevant research shows that between 1986 and 2008, the clinical use of enamel reduction anterior teeth increased by multiple fold [17].

IER has been widely used in the treatment of patients with malocclusion and dentition crowding. For patients who are not willing to wear dental braces for a long time during the orthodontic treatment, dentists usually use expansion to adjust the patient's dentition, which is difficult to operate and prone to recurrence. With the application of IER, the above problem can be solved, which also effectively shortens the duration of treatment and was easily accepted by patients. During the treatment of patients with molar anchorage and more forward molar design, there are adverse reactions such as backward tooth inclination and the deepening of the curve of Spee. Therefore, conservative treatment with non-extraction should be designed as much as possible in invisible orthodontic treatment. The majority of patients using invisible correction have been adults, which require simplified treatment with shortened course. In addition, the patients that have high mineralization of permanent teeth and varying degrees of gingival atrophy are also deemed suitable for IER.

Twesme et al. [18] found that clinical IER operation produces irregular groove marks on the IER surface. The uncleanness of these surfaces increases the exposure area of enamel in the mouth. Compared with the tooth surface without IER operation, the surface after IER is more likely to suffer from oral diseases and caries. In

1956, Hudson [19] found that polishing and coating the tooth surface with fluoride after IER could prevent the occurrence of tooth diseases. The polishing methods can be divided into physical and chemical techniques. The physical polishing method mainly uses friction tools such as polishing needle, polishing template and polishing floppy template to reduce the enamel roughness. Shu et al. [20] used different methods of IER in enamel reduction, and polishing experiments were conducted after IER. The results showed that the remineralization effect of the polishing group was better than that of the unpolished group, and there was no substantial difference between different IER methods in the degree of enamel remineralization. Fu et al. [21] treated the enamel on the tooth surface by different polishing methods. Scanning electron microscopy observation revealed that all polishing methods could improve the smoothness of the enamel surface and reduce the risk of enamel demineralization. Furthermore, the chemical polishing method proved superior to other means. Based on the above researches, it can be found that it is necessary to polish the teeth surface after IER. To obtain better results, in our case, the patient was given chemical polishing, and low concentrated enamel acid etching agent was employed to reduce the roughness of tooth surface.

Currently, there are many researches regarding IER, while the accuracy of IER has not been sufficiently improved; clinicians can only judge the position and depth of grinding required through clinical experience. Especially for those patients with serious adjacent relationship between the teeth, they cannot precisely locate the contact surface that needs grinding. Therefore, during the traditional IER operation, the tooth surface may be ground inaccurately.

As demonstrated in this study, digital IER process technology, including laser scanning, 3D reconstruction, virtual tooth arrangement and 3D printing, can positively assist with the orthodontic treatment. The innovative design of IER guide template controls the reduction volume of IER, which provides a new procedure for accurate IER operation. Through a clinical application example, we clearly illustrated that the use of guide template can not only protect the gingival tissue and dentin of patients from damage, but also achieve accurate positioning of the reduction area. In addition, when the dentist conducts the IER operation, it is not necessary to measure repeatedly, which simplified the process of IER.

In practice, due to the limitation arising from the patient's open-mouthed position, the space for IER operation is restricted and the accuracy of the IER guide template is affected in some areas with serious malocclusion. In the actual IER operation, there is some deviation at certain regions with serious malocclusion because at these areas, the IER process is not convenient for reduction. Therefore, we designed an appropriate IER scheme according to the situation of the patient's mouth. The same is recommended for the future cases. Additionally, the use of transparent material in the fabrication of IER guide template is encouraged to clearly observe all the important regions. As presented in this study, the use of digital technology to optimize the IER operation, such as (i) reducing the error of IER, (ii) reducing the difficulty of operation, and (iii) the time of correction, is inevitable for more satisfactory results.

Conclusions

The accuracy of IER plays a crucial role in orthodontic treatment outcomes. This study demonstrates that digital methods can precisely calculate the area and volume of IER, and the use of static navigation significantly enhances the precision and efficiency of the operation. In our clinical case, the guide plate-assisted IER achieved a smaller standard deviation (0.13 mm) compared to the free-hand method (0.24 mm) and reduced operational time. This highlights the clinical feasibility and advantages of static guided IER method. Future research could further validate this method through large-scale clinical trials and investigate factors affecting its accuracy.

Materials and methods

Process of digital IER scheme

The schematic design process of digital IER methodology is depicted in Fig. 3 Initially, the dentition of the patient is scanned with intraoral scanner or plaster model scanner, and the 3D digital model is reconstructed based on the scan data. Then, the malocclusion dentition is arranged, and the volume for IER are obtained by matching and subtracting between the original dentition and the aligned dentition, as well as the digital IRE scheme. Subsequently, a corresponding IER guide template is designed according to the scheme and fabricated by 3D printing. Combined with the IER guide template, the IER tools are selected to assist the dentist with performing accurate clinical IER operation.

Data acquisition

A 24-year-old male patient from the Department of Stomatology of Zhejiang Provincial People's Hospital was selected as an example case for investigation. The main dental problems were uneven dentition, mild crowding of teeth, skeletal-class-I and angle-class-I malocclusions. Both the upper and lower dentitions needed orthodontic treatment. The intraoral orthosis is shown in Fig. 4.

The plaster models of the upper and lower dentitions of the patient were obtained using impression materials. The AutoScan-DS200 scanner (Shining 3D Tech Co., Ltd, Hangzhou, China) was used to scan the plaster model. Models in STL (Standard Triangulation Language) file can be exported by the software of AutoScan-DS200 scanner, with an accuracy within 0.015 mm. Compared with the removal amount of 0.2–0.5 mm

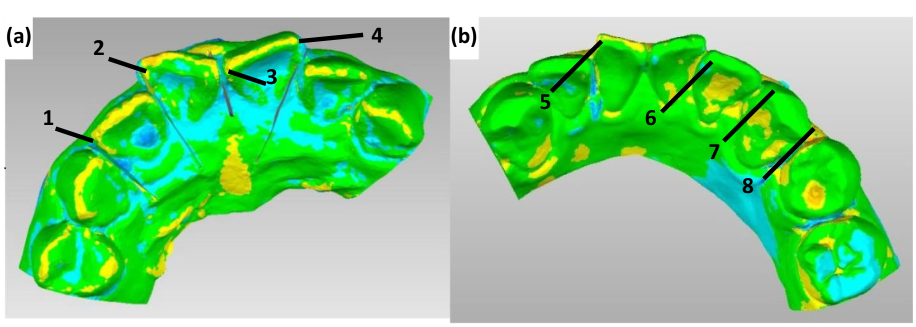

Fig. 3 Error analysis of IER: **a** maxilla with guide template, **b** mandibular without guide template

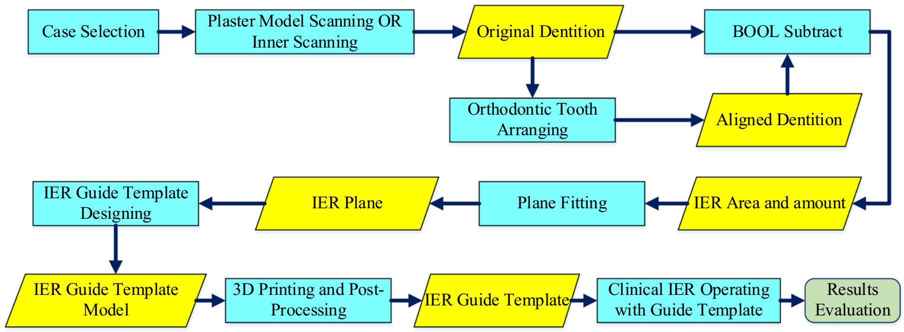

Fig. 4 Technical process of digital IER solution

Table 2 Patient crown width

Dental number	17	16	15	14	13	12	11
Crown width (mm)	10.85	11.32	7.13	8.23	8.15	8.04	8.85
Dental number	21	22	23	24	25	26	27
Crown width (mm)	8.96	7.95	8.10	8.08	7.61	11.06	11.01
Dental number	47	46	45	44	43	42	41
Crown width (mm)	11.65	12.18	8.25	8.14	7.43	6.49	6.08
Dental number	31	32	33	34	35	36	37
Crown width (mm)	5.46	6.54	7.58	8.03	8.40	12.17	12.13

per tooth, the error of the AutoScan-DS200 scanner has no significant impact on the experimental results. The scanned digital plaster models were imported into Geomagic Studio (V12, 3D system, Rock Hill, SC, USA) via STL files. The holes and gaps of the model were filled and repaired to obtain a complete model.

Arrangement of digital teeth

The digital dentition data were imported into Magics (V13.1, Materialise NV, Leuven, Belgium) and each tooth was separated from the dentition using a cutting tool to obtain the upper dentition with separated teeth. During cutting, we ensured that the cutting line was located between two adjacent teeth rather than cutting the crown into two parts. Bolton index analysis was performed before tooth arrangement.

Each segmented tooth was successively imported into Magics, and the crown width of each tooth was assessed by the measuring tool. The crown of each tooth was measured three times and averaged. The crown width of the patient was obtained as shown in Table 2. The measurement showed that the anterior tooth ratio of the patient was 79.08%, and the total tooth ratio was 96.16%. According to the Bolton index of Chinese people, the anterior tooth area of males is 78.58 ± 2.36%, and the full tooth ratio is 91.05 ± 1.40% [11]. In our case, the patient had too many teeth on the lower side than the upper side, and the posterior region of the lower side was crowded. Therefore, the number of upper teeth of this patient was relatively normal. The upper dentition was aligned first, followed by the lower dentition. The position of each separated tooth was adjusted by using the translation and rotation tool of Magics. With the guidance of the orthodontist, the digital arrangement of teeth was carried out according to the standard items of normal jaw.

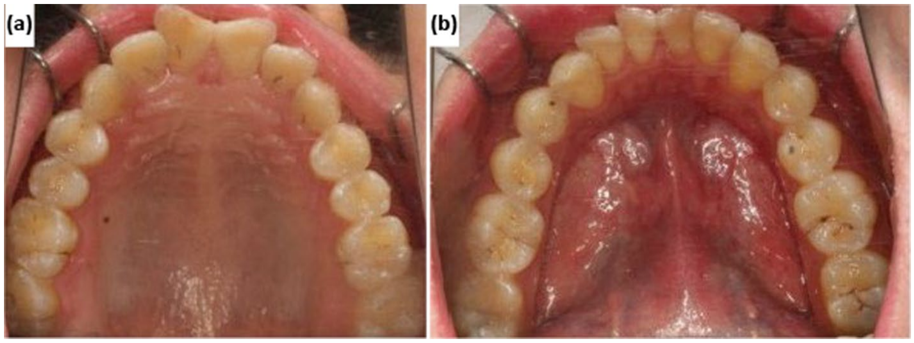

Fig. 5 Inside view photograph before IER: **a** maxilla, **b** mandibular

Design of IER guide template

According to most clinicians, the thickness of IER should not exceed 50% of the adjacent enamel thickness, and the IER thickness of anterior teeth should be less than that of posterior teeth. The enamel thickness of normal teeth ranges from 0.75 mm to 1.25 mm, and the safe limit of tooth enamel removal is less than 0.6 mm. Therefore, in our patient, a maximum gap of 9.6 mm could be obtained by employing adjacent IER technology.

In order to realize the IER scheme in clinical practice, an IER guide template of operation was designed and fabricated to assist the doctor with completing the IER operation. The IER guide template should have good retention in the patient's mouth, and a stable structure and moderate size, which does not affect the operation.

The gypsum data scanned from the patient were imported into the six-dimensional dental implant design software TM (6D Dental, Hangzhou, China). The initial model of the dental template was obtained by referring to the design method of the implant guide template. According to the volume of IER, the model of IER guide template was obtained by BOOL subtraction of the initial model and IER area. The guide template could be fixed on the dentition by 9 teeth, and the other part was removed. As shown in Fig. 5a, the IER guide template was matched on the digital model of the patient. The IER guide template was fabricated by a Form 3B + printer (Formlabs, Somerville, USA) with biocompatible resin, which is suitable for medical application. After the post-processing of 3D printing, the final template model was obtained and tested on the gypsum model, as shown in Fig. 5b.

Clinical experiment with the IER guide template

Before the clinical operation, the IER guide template and other dental instruments needed for IER were disinfected. The dental chair and light were adjusted to avoid malaise caused by improper posture. When grinding the tooth surface, the actions should be simple and accurate, using a diamond strip to grind off the area of tooth guided by the gaps on the guide template, as shown in Fig. 5c. In the control group, the lower dentition of patient was adjusted by free-hand IER operation according to the digital scheme. The same diamond strip was used in both experiments.

Acknowledgements
The authors have no acknowledgments.

Author contributions
The study was conceptualized by J You, XY Zhou and YF Liu, who were also responsible for the design for this study. J You and XF Xia designed the experimental scheme. The IER guide template was designed and fabricated by XF Xia. The subject recruitment and clinical operation were performed by JX Zhang. The digital model was processed by XY Zhou and XF Xia, who were also carried out the data analysis. J You, XY Zhou and XF Xia drafted the manuscript, with JX Zhang and YF Liu provided editing and revision. The resources for the study were obtained by YF Liu. All authors have read and approved the final manuscript.

Funding
This work was supported by the National Natural Science Foundation of China (No. 52175280), the Zhejiang Provincial Natural Science Foundation of China (No. LD22E050013).

Data availability
No datasets were generated or analyzed during the current study.

Declarations

Ethics approval and consent to participate
The study was approved by the ethics committee of Zhejiang Provincial People's Hospital. All methods in this study were in full compliance with the Declaration of Helsinki and other relevant guidelines. We declare that Informed Consent was obtained from the subject prior to the experiment.

Competing of interest
The authors declare no competing interests.

Received: 26 July 2024 Accepted: 6 January 2025
Published online: 15 January 2025

References
1. Proffit WR, Sarver DM, Fields HW. Contemporary orthodontics. Philadelphia: Elsevier/Mosby; 2019.
2. Bamashmous MS. Veneer or interproximal enamel reduction? J Contemp Dent Pract. 2018;19(6):749–51. https://doi.org/10.5005/jp-journals-10024-2330.
3. Panchal N, Mahmood L, Retana A, Emery R. Dynamic navigation for dental implant surgery. Oral Maxillofac Surg Clin North Am. 2019;31(4):539–47. https://doi.org/10.1016/j.coms.2019.08.001.
4. Kravitz ND, Kusnoto B, BeGole E, Obrez A, Agran B. How well does invisalign work? A prospective clinical study evaluating the efficacy of tooth movement with invisalign. Am J Orthod Dentofac Orthop. 2009;135(1):27–35. https://doi.org/10.1016/j.ajodo.2007.05.018.
5. Cruz M, Lourenço AF, Toledo EM, da Silva Barra LP, de Castro Lemonge AC, Wassall T. Finite element stress analysis of cuneiform and cylindrical threaded implant geometries. Technol Health Care. 2006;14(4–5):421–38. https://doi.org/10.3233/thc-2006-144-523.
6. Zor ZF, Kılınç Y, Erkmen E, Kurt A. How do implant threads and diameters affect the all-on-four success? A 3D finite element analysis study. Technol Health Care. 2022;30(5):1031–42. https://doi.org/10.3233/thc-213072.
7. Wu JL, Liu YF, Zhang JX, Peng W, Jiang XF. Biomechanical investigation of orthodontic treatment planning based on orthodontic force measurement and finite element method before implementation: a case study. Technol Health Care. 2018;26:347–59. https://doi.org/10.3233/thc-174689.
8. Liu YF, Zhang PY, Zhang QF, Zhang JX, Chen J. Digital design and fabrication of simulation model for measuring orthodontic force. Bio-Med Mater Eng. 2014;24(6):2265–71. https://doi.org/10.3233/bme-141039.
9. De Felice ME, Nucci L, Fiori A, Flores-Mir C, Perillo L, Grassia V. Accuracy of interproximal enamel reduction during clear aligner treatment. Prog Orthod. 2020. https://doi.org/10.1186/s40510-020-00329-1.
10. Hariharan A, Arqub SA, Gandhi V, Da Cunha GL, Kuo CL, Uribe F. Evaluation of interproximal reduction in individual teeth, and full arch assessment in clear aligner therapy: digital planning versus 3D model analysis after reduction. Prog Orthod. 2022. https://doi.org/10.1186/s40510-022-00403-w.
11. Lin JX. Modern orthodontics. Beijing: Beijing People's Press; 1991.
12. Ballard ML. Asymmetry in tooth size: a factor in the etiology, diagnosis and treatment of malocclusion. Angle Orthod. 1944;14(3):67–71.
13. Begg PR, Kesling PC. Orthodontic appliances in Begg orthodontic theory and technique. Ann Arbor: WB Saunders Company; 1977.
14. Stroud JL, English J, Buschang PH. Enamel thickness of the posterior dentition: its implications for nonextraction treatment. Angle Orthod. 1998;68(2):141–6.
15. Zachrisson BU. Interdental papilla reconstruction in adult orthodontics. World J Orthod. 2004;5(1):67–73.
16. Livas C, Jongsma AC, Ren Y. Enamel reduction techniques in orthodontics: a literature review. Open Dent J. 2013;7(1):146–51. https://doi.org/10.2174/1874210601307010146.
17. Keim RG, Gottlieb EL, Nelson AH, Vogels DS 3rd. 2008 JCO study of orthodontic diagnosis and treatment procedures. Part 3: more breakdowns of selected variables. J Clin Orthod JCO. 2009;43(1):22–33.
18. Twesme DA, Firestone AR, Heaven TJ, Feagin FF, Jacobson A. Air-rotor stripping and enamel demineralization in vitro. Am J Orthod Dentofac Orthop. 1994;105(2):142–52. https://doi.org/10.1016/s0889-5406(94)70110-5.
19. Hudson AL. A study of the effects of mesiodistal reduction of mandibular anterior teeth. Am J Orthod. 1956;42(8):615–24. https://doi.org/10.1016/0002-9416(56)90103-8.

20. Shu CL, Liu XQ, Wang GF. Effect of different adjacent enamel removal methods on enamel. ShangHai J Stomatol. 2012;21(4):384–8.
21. Fu SM, Ding Y, Wang HX. Comparison of two enamel polishing methods after orthodontic bracket removal—SEM observation of enamel. Chin J Conserv Dent. 2004;14(6):319–21.

Publisher's Note