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RESEARCH AND EDUCATION

Preliminary application and evaluation of digital step-by-step tooth-preparation templates

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Tooth preparation is a fundamental irreversible technique in dentistry, and excessive or insufficient tooth preparation may lead to hard tissue damage or an inadequate restoration.[1,2] Traditional tooth preparation techniques are mostly visually guided and rely on the experience of the dentist.[3] Tooth preparation guiding techniques include the silicone index,[4] the depth-gauge method,[5] the occlusal record method,[6,7] and the trial restoration approach.[8] It has been reported that traditional visual guidance lacks measurability, controllability, repeatability, and accuracy.[9] Thus, it is difficult for dentists to precisely control the extent of tooth preparation, which may cause unnecessary loss of hard tissue.[10]

ABSTRACT

Statement of problem. Tooth preparation is a fundamental technique, and inaccurate preparation may lead to excessive irreversible tooth removal or insufficient restorative space. The conventional process depends mostly on operator experience, and variable quality is inevitable. Whether a tooth preparation template would be beneficial, especially for inexperienced dentists, is unclear.

Purpose. The purpose of this preliminary study was to evaluate the application of new digitally designed step-by-step templates to guide tooth preparation.

Material and methods. A laboratory scanner was used to obtain digital scans of dental casts. A 3-dimensional reverse engineering software program was used for the step-by-step digital design. The data for a series of guide templates were imported into a computer-aided manufacturing (CAM) machine for milling. Ten experts and 10 inexperienced dentists prepared teeth on a dentoform in a mannequin head. They were instructed to complete the preparation within 20 minutes both with and without the step-by-step template. The prepared crowns were subsequently scanned with an intraoral scanner, the scans were imported into a preparation evaluation software program, and various indexes were scored. The *t* test was used to analyze the differences between the 2 methods of tooth preparation in each group (α=.05).

Results. No significant differences were found in total scores with and without the guide templates in the expert group (P=.256), but the scores in the inexperienced group differed significantly between the 2 preparation methods (P<.001). In undercut comparisons, the 2 methods of preparation did not differ significantly in the expert (P=.912) or inexperienced groups (P=.601). However, the scores for taper and occlusal reduction were significantly higher in the inexperienced group when using the guide template (P<.001).

Conclusions. The new digitally designed step-by-step tooth preparation guide template significantly improved the efficiency and quality of tooth preparation for inexperienced dentists when preparing multiple teeth. (J Prosthet Dent 2023;130:102-7)

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Clinical Implications

As tooth preparation is experience-dependent, a guide template should help standardize the preparation process. For inexperienced dentists, the step-by-step guide template should improve the quality of their tooth preparations.

Minimally invasive dentistry has led to the development of new methods to reduce hard tissue removal and shorten operation times.[11,12] While surgical templates have been applied in maxillofacial and implant surgery to assist intraoperative positioning,[13-15] they can, theoretically, also be used for tooth preparation. However, studies on the application of digital guidance for tooth preparation are sparse. Taha et al[16] developed a 3-dimensionally (3D) printed digital preparation device to control the extent of tooth preparation to ensure adequate clearance for the restorative material, and Lee et al[17] designed a preparation guide to help prepare extensively worn dentition minimally and validate the extent of preparation. However, the authors are unaware of reports of full guidance assistance during tooth preparation.

Therefore, a new digitally designed step-by-step tooth-preparation template was developed to guide the entire process of preparation. The preliminary application of the template was evaluated in 2 groups of practitioners. The null hypothesis was that no difference would be found between preparation with and without the template.

MATERIALS AND METHODS

Twenty dentists from the Peking University School of Stomatology were divided into 2 groups based on their experience. The study was approved by the biomedical ethics committee of Stomatology Hospital, Peking University (ethical batch number: PKUSSIRB-201523084). Ten dentists who held associate senior titles or above were enrolled in the expert group; the other 10 were graduate students, who were included in the inexperienced group. The average clinical experience of the expert group was more than 10 years, whereas in the inexperienced group, it was less than 2 years. The right mandibular second premolar and first molar were prepared with or without the digitally designed step-by-step template. Random numbers were used in each group to determine the order of preparation by being placed in envelopes. Before the tooth preparation, the dentists of each group opened the envelope, and odd numbers stood for template first and even numbers for freehand first.

Dental casts were scanned with a cast scanner (D2000; 3Shape A/S) to obtain a digital scan of the maxillary and mandibular dentition; the scan data were saved as standard tessellation language (STL) files and then imported into a 3D reverse engineering software program (Geomagic Studio 2014; 3D Systems, Inc). The template design process comprised virtual tooth preparation, determination of rotary instrument head direction, and template shape design. Virtual preparation was carried out on the occlusal, buccolingual, and mesiodistal surfaces by using the standard amount of tooth preparation. During the actual preparation, the process was performed in steps. Once the template was seated, the corresponding preparation was implemented. In this study, cast metal complete crown preparations of the mandibular right second premolar and first molar were chosen as examples.

For the occlusal surface template, virtual preparation was performed as follows (Fig. 1A): The buccal and lingual cusps were manually selected, and the offset function was used to offset the selection area apically by 1.5 mm. Small surface fragments were removed. Then, a Ø1×20-mm cylinder was created to replicate the shape of the SR-11 diamond rotary instruments used in the tooth preparation. This was placed at the buccal cusp, lingual cusp, and lingual groove so that the removal direction of the occlusal surface could be determined. Subsequently, the shape of the template was formed virtually by the software program. A Ø20×30-mm cylinder was created on the dental cast and named shape 1. This was scaled and sculpted in different proportions in multiple directions to cover the buccolingual sides of the prepared crown. Shape 2 was obtained by Boolean subtraction between shape 1 and the prepared dental cast. Both the area occlusal to the abutment crown in shape 2 and the occlusal surface of the crown were deleted to form shape 3. According to the direction of the rotary instruments, some "bridges" were created between the outer surface of shape 3 and the axial surface of the crown to fill the internal hole. The shape of the template was modified to complete the design based on the occlusal shape (Fig. 1B).

The buccolingual and mesiodistal templates were then designed in sequence (Fig. 1C-F). Virtual preparation was carried out as follows: The central fossa of adjacent teeth was selected, and a fitting plane was created through the line of the selected fossa, which was regarded as plane 1. The cervical area of the crown was selected, and 0.5 mm was offset inward to form a ferrule. Plane 1 was taken as the axis, and plane 2 (buccal side) and plane 3 (lingual side) were created with an angle of ±3 degrees; they were moved to the cervical plane after inward offset as the preparation plane. The inward surface was selected and moved up to the occlusal surface along plane 2. Curve cutting was used to reduce the buccal area based on the intersecting line, and the internal hole was filled flat to form the buccal shape of the

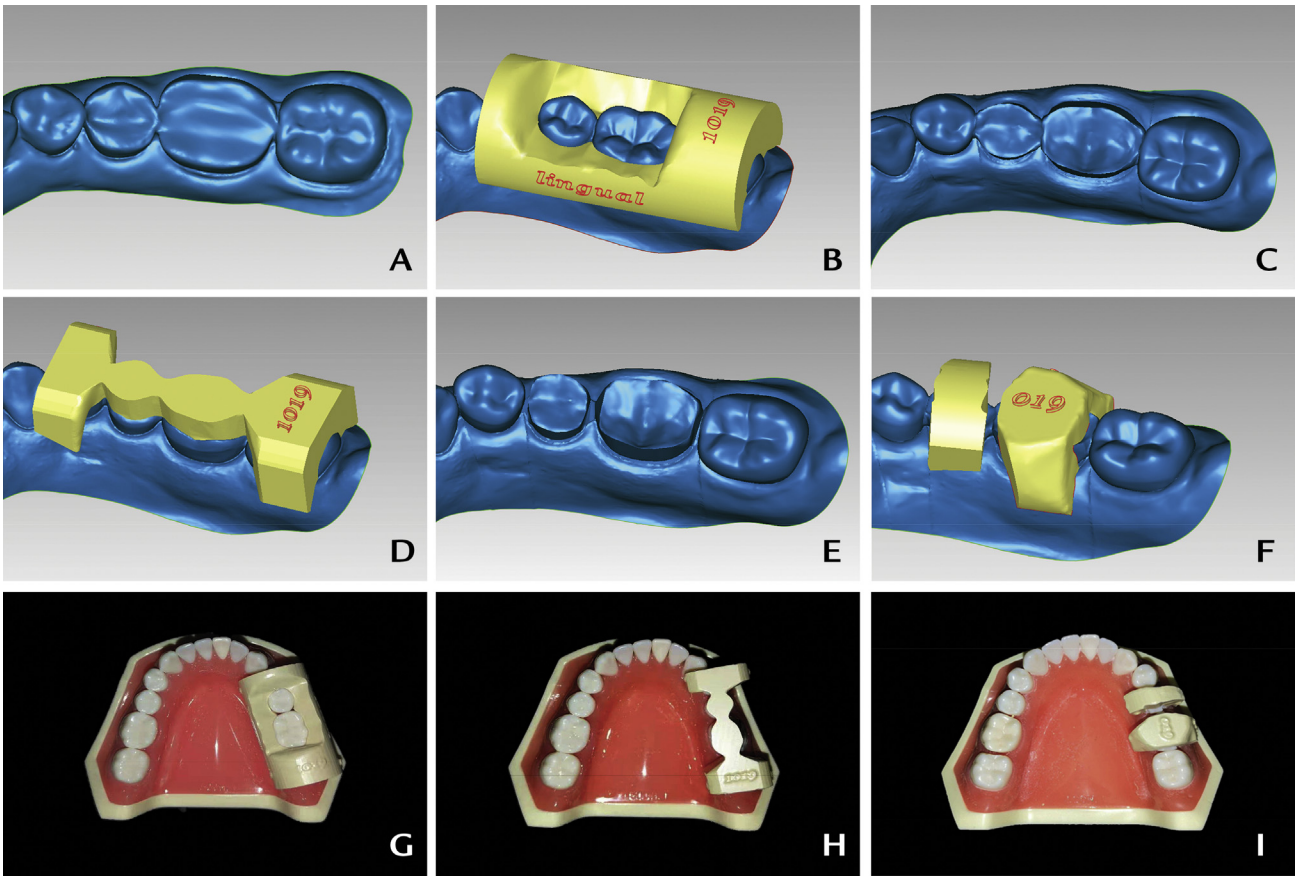

Figure 1. Design of step-by-step tooth preparation template. A, Virtual preparation of occlusal surface. B, Shape of occlusal template. C, Virtual preparation of buccolingual surface. D, Shape of buccolingual template. E, Virtual preparation of mesiodistal surface. F, Shape of mesiodistal template. G, Milled PEEK occlusal template. H, Milled PEEK buccolingual template. I, Milled PEEK mesiodistal template. PEEK, polyetheretherketone.

prepared crown. The same method was also performed on the lingual, mesial, and distal surfaces. A similar cylindrical shape was also created and placed in the axial ridge and the axial groove. The shape design of the buccolingual and mesiodistal surfaces template replicated that of the occlusal surface template.

The STL file of the designed templates was sent to a dental laboratory and was imported into a digital milling software program and machine (Organical Mill 2.0; Organical CAD/CAM GmbH). In the present study, wet milling was performed on a polyetheretherketone (PEEK) tray (BioPAEK; Dentex) by subtraction processing (Fig. 1G–I). This material has been evaluated for digital production of dental prostheses with reportedly good machinability and rigidity.[18-20] The templates were then sent to the clinic to evaluate the preliminary application of tooth preparation.

Two groups of dentists were instructed to prepare teeth on a dentoform in a mannequin head with or without the template with a time limit of 20 minutes. After the preparation, the casts with prepared teeth were then scanned (CEREC Omnicam; Dentsply Sirona). The virtual crown abutments were all imported into an evaluation software program (CEREC prepCheck; Dentsply Sirona) to assess preparation quality,[21,22] evaluating undercut, taper, and occlusal reduction. The assessment standards were modified according to the criteria developed by the American Board of Dental Examiners. Among them, the taper tolerance value was 4 to 12 degrees, and the occlusal reduction was 1.0 to 2.0 mm. In addition, a comparison between the preparation and the built-in cast in the software program was also performed (total scores).

The assessment results were transformed into scores that included the total score and detailed scores for several indexes (taper, undercut, and occlusal reduction). The scores were statistically analyzed with a software program (IBM SPSS Statistics, v20.0; IBM Corp) by using the 2-sided *t* test (α=.05).

RESULTS

There were no significant differences in total tooth preparation scores in the expert group (Table 1) between preparation with and without the guide (*P*=.256). However, the scores in the inexperienced

Table 1. Total scores for tooth preparation in 2 groups

Group	With Guide	Without Guide	t	*P*
Expert	89.0 ±3.5	87.5 ±2.3	1.212	.256
Inexperienced	87.7 ±4.4	78.7 ±4.8	5.570	<.001

group differed significantly between the 2 preparation methods ($P<.001$). The crowns prepared with the template had higher scores than those prepared without the template.

The results of the detailed indexes (taper, undercut, and occlusal reduction) are shown in Table 2 and Figure 2. The color blue indicates that preparation was within the tolerance of the set value, while red and green indicate that tolerance values were exceeded.

Undercut preparation by using either method did not differ significantly in the expert ($P=.912$) or inexperienced groups ($P=.601$), but scores for taper ($P=.002$) and occlusal reduction ($P<.001$) differed significantly in the inexperienced group. In this group, those who used the step-by-step template had higher scores in taper assessment. Neither of the scores for taper ($P=.549$) or occlusal reduction ($P=.144$) showed significant differences in comparison with the expert group.

Table 2. Undercut, taper, and occlusal reduction scores for tooth preparation in 2 groups

Group	With Guide	Without Guide	t	*P*
Undercut				
Expert	99.2 ±1.3	99.3 ±1.0	-0.114	.912
Inexperienced	99.0 ±1.4	98.5 ±1.5	0.542	.601
Taper				
Expert	78.9 ±2.9	79.8 ±3.4	-0.622	.549
Inexperienced	76.2 ±5.9	62.2 ±7.1	4.213	.002
Occlusal reduction				
Expert	85.4 ±2.9	83.3 ±4.6	1.599	.144
Inexperienced	84.1 ±2.7	75.2 ±4.6	5.470	<.001

DISCUSSION

The null hypothesis was partly accepted as, in the expert group, the use of the new template did not affect the tooth preparation quality. However, the inexperienced group showed significant differences in total scores and taper scores; the crown abutments prepared when using the template had better scores than those prepared without it.

Tooth preparation is the basis of dental restorative treatment. In the present study, during the same time limit of 20 minutes, the experts performed consistently while the inexperienced dentists had greater variation. For the inexperienced, the teeth prepared freehand included excessive irreversible tooth removal or insufficient restorative space, resulting in adverse effects on the definitive prosthesis or natural tooth. Therefore, precise guidance for tooth preparation is of considerable benefit.

The development of computer-aided technology has led to studies of guided tooth preparation.[16,17] However, these studies were directed primarily at the depth of tooth preparation. The results of axial surface preparation may also be affected by experience, and evaluation standards for tooth preparation are still unclear. Therefore, a digitally designed tooth-preparation template was developed and evaluated by prosthodontists on a dentoform in a mannequin head. The series of templates had 3 components: occlusal, buccolingual, and mesiodistal. The dentists used them in this sequence. The template can also verify the quantity of material removed and whether each step meets a required standard.

Virtual tooth preparation is a necessary step in the template-design process. A cast of a standard abutment crown determined the accuracy of the guide template. In the present study, virtual tooth preparation was performed in a sequence that ensured the precision of each step in the template design. The approach was modified from the digital design method introduced by Yuan et al[11] in 2015. It was also expanded from a single crown to multiple crowns, and the taper and preparation amounts were both specified to meet clinical acceptance.

The results of the present study showed that the template helped the inexperienced dentists to improve their tooth preparation quality. During the preexperiment period of this study, the effect of template for a single tooth (the right mandibular first molar) had also been performed, but operator experience did not significantly affect the results, possibly because of a relatively easier preparation. The present study involved preparing 2 teeth, and the total scores showed that the inexperienced group improved with the use of the template ($P<.001$).

The present study illustrates that tooth preparation is an experience-oriented operation. Lack of experience and proficiency will adversely affect the time and quality of preparation and may lead to a loss of confidence and diminish the learning motivation of the operator.[10] Through the artificial-to-digital transfer, the digital step-by-step tooth preparation template realized a complete digital workflow, guided practical clinical preparation, transferred virtualization to reality, improved preparation efficiency, and lowered technique sensitivity, thus lowering the risk of unwanted hard-tissue loss.

In the present study, prepCheck, a software program that has been widely used to evaluate tooth preparation quality in recent years, was used for the evaluation and provided relatively objective results for each group. Miyazono et al[21] assessed intragrader and intergrader agreement by using prepCheck in comparison with the

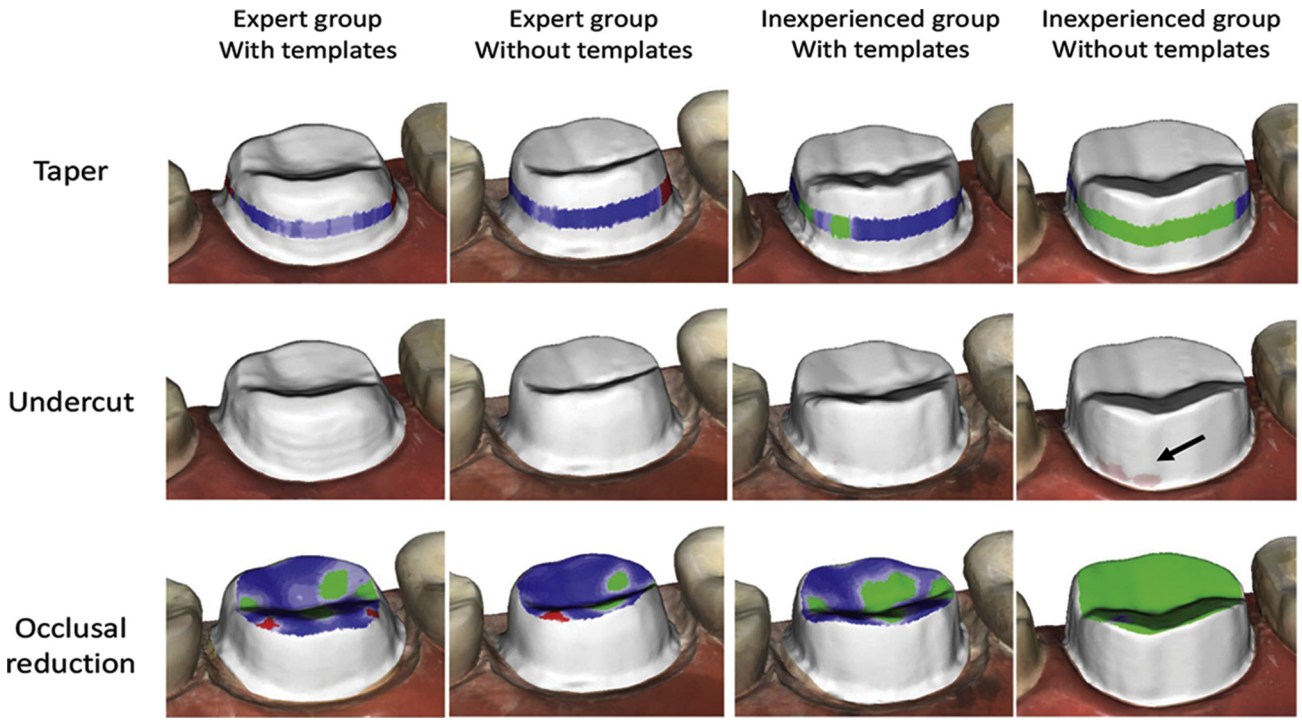

Figure 2. Results of CEREC prepCheck evaluation. *Red* and *green* indicate exceeding tolerance and *blue* indicates within tolerance. For taper evaluation, *red* indicates taper more than 12 degrees while *green* indicates taper less than 4 degrees. For occlusal reduction, *red* indicates reduction more than 2 mm while *green* indicates reduction less than 1 mm. Different *blues* indicate gradual averagely distributed values within tolerance. *Black arrow* indicates detectable undercut.

current traditional visual grading method in a dental student simulation laboratory, indicating that it greatly improved intragrader and intergrader agreement during the grading process. Schepke et al[22] evaluated prep-Check as a tool for assessing the practical skills of students and as a means to provide feedback in dental education; they reported that although additional time and equipment were needed, most students appreciated the software program. The corresponding standard parameters can be individually input into the software program in accordance with the different restoration types.

PEEK has a wide range of applications in dentistry and was used for the guides in the present study.[18-20,23] Combined with previous results, the present study indicated that PEEK has better wear resistance than polymethyl methacrylate (PMMA).[24] In addition, 3D printing is also feasible from the STL files. Dentists can easily retrieve the original data to review and modify in response to the digital workflow. Interim crowns can also be manufactured in advance to reduce patient visits and clinical time.

Limitations of the present study included the need for the dentists to finish the preparation manually and that the templates were not significantly helpful in increasing the efficiency of experts. In addition, the templates were more helpful when preparing multiple teeth because their benefit increased with the number of teeth. Specifically, preparation could be achieved by limiting the rotary instrument head angle and length of structures based on the template design. The results of the present study showed that excessive tooth preparation was largely eliminated. With continued progress in technology and innovation, a more convenient, minimally invasive, and accurate template manufacturing method will emerge.

CONCLUSIONS

Based on the findings of this preliminary study, the following conclusion was drawn:

1. The new digitally designed step-by-step tooth preparation guide template significantly improved the efficiency and quality of tooth preparation for inexperienced dentists performing multiple teeth preparations.

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CRediT authorship contribution statement
Shimin Wang: Methodology, Software, Writing – original draft. **Weiwei Zhao:** Methodology, Software, Formal analysis. **Hongqiang Ye:** Methodology, Data acquisition. **Yunsong Liu:** Conceptualization, Methodology, Writing – review & editing. **Yongsheng Zhou:** Financial support, Writing – review & editing.

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