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Original Article

Automatic Evaluation of Crown Preparation Using Image Processing Techniques: A Substitute to Faculty Scoring in Dental Education

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Abstract

Background: This study presents a new and innovative experimental method, including software and its prerequisite instruments, to use image processing techniques for crown preparation analysis. **Method:** A platform was designed and constructed to take images from artificial teeth in different angles and directions and to process and analyze them by the proposed method to evaluate the quality and quantity of crown preparation. For each tooth, two series of images were taken from the artificial teeth before and after preparation, and image series were registered by two semi-automated and automated methods to transform them into one coordinate system. Region of interest was segmented by user interaction, and tooth region was segmented by substeps such as transformation to hue, saturation, and value color space, edge detection, morphology operations, and contour extraction. Finally, the amount and angle of crown preparation were computed and compared with standard measures to evaluate the quality of crown preparation. The proposed method was applied to a local dataset collected from Isfahan University of Medical Sciences. **Results:** Difference between the angle of crown preparation computed by the proposed method and that of the experts showed a mean absolute error of 7.17°. The correlation between the segmented regions by the proposed method and those of the experts was also evaluated by the Intersection over Union (IOU) criterion. The best and worst performances achieved in cases by IOU were 0.94 and 0.76, respectively. Finally, the segmentation results of the proposed method indicated an average IOU of 0.89 in all images. **Conclusion:** Students can use this method as an assessment tool in preclinical tooth preparation to compare their crown work with standard parameters.

Keywords: *Assessment, computer-assisted image processing, dental education, grading, preclinical simulation, prosthodontic tooth preparation*

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Introduction

Teeth do not possess the regenerative ability found in most other tissues. Therefore, once enamel or dentin is lost, restorative materials must be used to reestablish form and function.[1] Crown preparation is essential before the restoration stage, and preparations must be based on fundamental principles to establish basic criteria to predict the success of care in the future.[2]

In dentistry, crown is one of the most widely used fixed restorations. The restoration process consists of three groups: full metal, metal-ceramic, and full ceramic crowns. A full metal crown is a full-coverage metal restoration with a low level of esthetic options. A metal-ceramic crown is a full-coverage cast metal crown covered with a layer of fused porcelain to reproduce the aspect of natural tooth in both shape and color.[3] All-ceramic crowns are the most pleasing esthetic restorations which mimic the original tooth color better than other restorative options.[4]

Such a restoration requires specific tooth reduction to provide space for metal and/or ceramic layers of crown along with tooth structure preservation. Crown preparation requires considerable tooth reduction, leads to appropriate shape and thickness, and guarantees natural tooth duplication and structural durability. Insufficient tooth reduction may lead to a compromised appearance of restoration, and overcontoured restorations may appear at expense of proper axial contour, which leads to periodontal diseases. Sufficient tooth removal is needed to provide a distinct

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fishing line to host the material.[5] The recommended reduction in literature for different materials and views of tooth ranges from 0.7 in full metal to 2 mm in all-ceramic crowns.[6]

An appropriate degree of taper for crown preparation is also another important aspect in crown preparation. A too-small taper may lead to unwanted undercuts, causing unfitted restoration and possible tooth decay or tooth loss. A too-large taper leads to frequent decementation of the crown. Textbooks in fixed prosthodontics often recommend a convergence angle (CA) of approximately 5° (4°–6°) as ideal and a range of 4°–14° as acceptable.[7,8] However, these guidelines are difficult to follow clinically, and divergence from parallel might have to be as much as 12° to be observed clinically as a diverging surface. Mack observed that a minimal taper of 12° was necessary to ensure the absence of undercuts.[9] Goodacre proposed that the total CA should range from 10° to 20°.[10] Other researchers have recommended 10° and 16° CA based on laboratory studies.[8] The recommended convergence between opposing walls is 6°, which is shown to optimize the retention of the crown. One of the most important components of dental education is preclinical fixed prosthodontics. Achieving proper skills in this domain is vital for becoming the next dentist. Progress for students in this field depends on hard practice, and one of the effective ways to provide students with efficient practice is developing a self-examination system.

There are several methods to evaluate the quality and quantity of preparation. The most accurate method to evaluate crown preparation includes making a proper impression, producing stone die, carrying out a two-dimensional scan of it, and measuring the preparation thickness and CA.[2] This method is not practical in a preclinical laboratory for several students due to time restrictions and need for additional steps. The current feasible method to evaluate preparation is undercut detection by an expert using visual techniques. There is no doubt that subjective evaluation suffers from intersubjective differences and is a time-consuming process to be used, which suffers from the level of expertise and the grading methods used.[11]

In recent decades, as a result of continual developments in digital dental technology and to improve the traditional techniques of evaluation, dental education has started to use digital technologies in various preclinical trainings[12] including tooth preparation. However, many of the available techniques require complicated equipment and enough time to work.

Computer-aided systems that offer many feedback options and self-assessment ability are used in different dental schools around the world. The Simodont Dental Trainer (ACTA, Amsterdam, The Netherlands) enables students to develop their manual skills in a realistic virtual world while getting feedback on their decisions and abilities. Sirona (Salzburg, Austria) describes its prepCheck as an easy-to-learn application that is based on objective measurement procedures with the ability to document and analyze students' results.[13] However, studies conducted to evaluate its effectiveness in dental education revealed that some students complained about working with this system and believed that introducing prepCheck requires enough equipment and preparation time.[14,15]

Recently, E4D Compare software program (Richardson, TX, USA) has also been introduced with the ability to evaluate the prepared teeth by the three-dimensional (3D) technique.[16] Although the instruments described above have been shown to have successful outcomes, they are based on high-tech and high-price scanner systems. Further, in these systems, the teeth prepared by students need to be compared with the ones prepared by their supervisors, which poses the evaluation at risk of human judgment again. Besides, for E4D system, it was shown that the conventional grading by the faculty was not located within an acceptable range derived using this software.[17] In another study, grades generated from a digital grading software (Nissan Fair Grader 100, Nissin Dental Products Inc., Kyoto, Japan) of students' preclinical assignment were compared with four calibrated faculty members. This software is able to scan a student's prepared tooth and compares it to a known (software-driven) standardized preparations, and it was revealed that the agreement between scores produced by the digital system and the scores of the examiners was mostly in the low-to-moderate range.[18] Finally, in another study,[19] feasibility of a tooth preparation assessment software referred as Preppr was evaluated as an assistant and educational tool for dental students for comparison of their crown preparation parameters with standard and optimal parameters.

The proposed method presents a device to calculate an immediate and accurate measurement of tooth preparation for dentistry students. A simple portable device with reasonable price and reliable measurement can play a vital role in improving the students' skills and helping them to achieve proper levels of skills during their academic education. In this study, we introduce and evaluate the efficacy of a new and innovative experimental method, including a piece of software and its prerequisite instruments, using image processing techniques in order to remove the role of the faculty in assessment of students' work in preclinical tooth preparation.

Materials and Methods

This study is based on the results of a technology-based research approved by the research council of Isfahan University of Medical Sciences, and the invention is approved by the Intellectual Property Center of State Organization for Registration of Deeds and Properties, Iran (No 98352). The block diagram of the whole process is shown in Figure 1.

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Figure 1: Block diagram of the proposed method

In this research, a piece of software is designed and implemented in Qt platform with C programming language and open CV image processing libraries. Qt is a technology strategy, which lets that programmers quickly and cost-effectively design, develop, deploy, and maintain software while delivering a seamless user experience across all devices. The software has a graphical user interface in which tooth images can be easily loaded and crown preparation parameters are computed and compared with parameters achieved from gold standard images. The source code of this software will be publicly available after the publication of the study. To make use of this software, a prerequisite instrument is designed to hold the sample tooth in a determined location and the imaging is simply done by mobile cell phones. The designed instrument is compatible with almost any cell phone with different sizes and different location of the camera due to flexible parts.

In other software packages such as E4D,[16] the crown prepared by students is scanned with 3D methods and then compared with 3D scans of the crown prepared by individual faculty members as gold standard cases. However, in proposed method, the parameters of crown preparation are computed automatically by image processing techniques on images acquired with mobile cell phones, with no need to complicated 3D scanners. The extracted parameters can be compared with standard and predefined parameters to evaluate the crown preparation qualitatively and quantitatively. This simple and efficient scheme is the main novelty of the proposed software compared to available methods.

Image registration

In the first step, for each tooth, two sets of images are taken from the artificial teeth before and after crown preparation. Photographs were taken using an instrument (box) prepared for this purpose. Camera positions are set in the instrument to make images in 0° and 90° with respect to the horizontal surface (referred as facial and occlusal images, respectively). For this purpose, two adjustable holes, above and in the proximal side, are made, which enables the users to take two images from the facial and occlusal sides. Adjustable holders are designed to adapt to different cell phones. Inside of the box is colored in black, and a set of light sources are spread around the box room to provide the best image quality with the least possible shadow effect. Furthermore, a special place is added to the box room to settle the plastic arc, and a graded movable platform is designed to enable the students to re-settle the arc in its exact place to take fully registered post images.

In this study, the images before and after crown preparation are called the FirstImg and SecondImg, respectively [Figure 2]. Four images are then stacked to calculate crown preparation parameters. The first step in parameter calculation is image registration, which is the process of transforming different sets of images into one coordinate system. Here, two procedures are examined for image registration.

The first method is a semi-automated method with user interaction. In this method, four points are selected by the user from the FirstImg, followed by selecting four corresponding points from the SecondImg. Then, a transform is found by homographic functions to map the first four points to the second ones. The presence of eight anonymous parameters in homographic functions justifies the need for four points.

The second method is an automated method in which two sets of key points from the FirstImg and SecondImg are detected by a surf detector[20] and then are described by local descriptors. In the next step, the best match between the points among the two sets is found and a transform is computed to provide a registration for the matched points. The registration result of FirstImg and SecondImg is shown in Figure 3.

Extraction of region of interest

In this specific application, region of interest (ROI) is a limited region located around the prepared tooth. The calculations showing the quality of preparation become very difficult if the region is not limited around the tooth of interest. Therefore, ROI is selected by the user interaction by mouse drag, resulting in a rectangular ROI. Figure 4 shows a sample occlusal image before and after the ROI selection.

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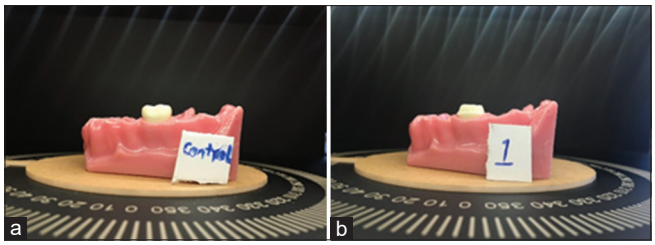

Figure 2: (a) First image: Facial image before crown preparation, (b) second image: Facial image after crown preparation

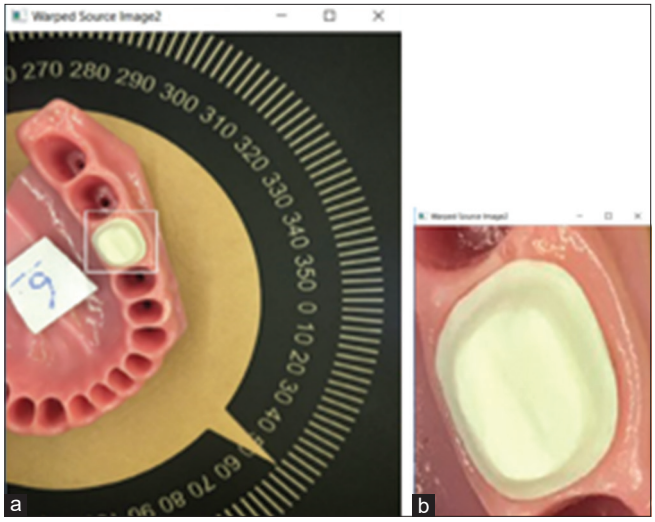

Figure 4: (a) Original occlusal image, (b) Selected region of interest

Figure 6: The result of Canny edge detector on selected region of interest from occlusal image in Figure 5

Tooth segmentation

The main goal of this research is to localize the tooth boundary and compute crown preparation parameters. For this purpose, the following steps are applied sequentially.

Transform to hue, saturation, and value color space

To discriminate the background region from the ROI, color differences are utilized. For this purpose, hue, saturation, and value (HSV) color domain provides a better representation than red, green, and blue (RGB) color coding.[21] In the first step, the reference ranges of H, S, and V components are considered for tooth regions empirically. Then, the HSV components of each pixel are

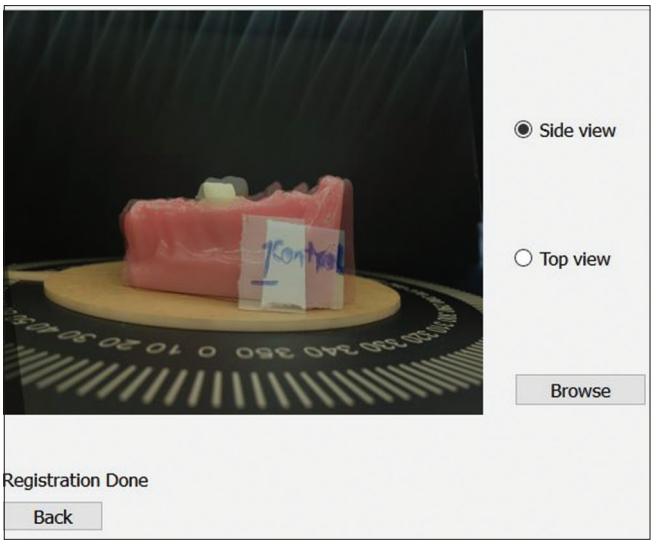

Figure 3: Facial image after registration of FirstImg and SecondImg

Figure 5: A binary occlusal image achieved from thresholding in hue, saturation, and value color domain

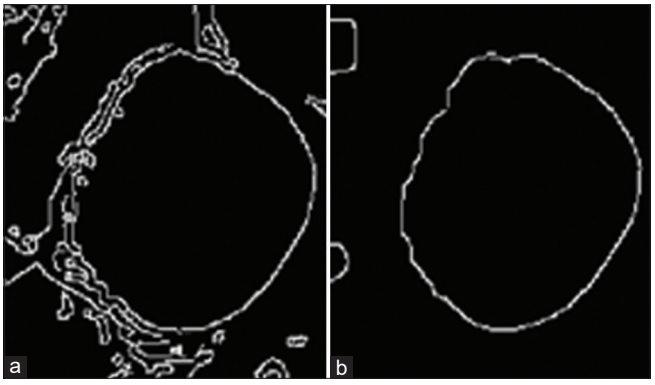

Figure 7: Effect of erosion operation. (a) Sample edge detected image before and (b) after erosion

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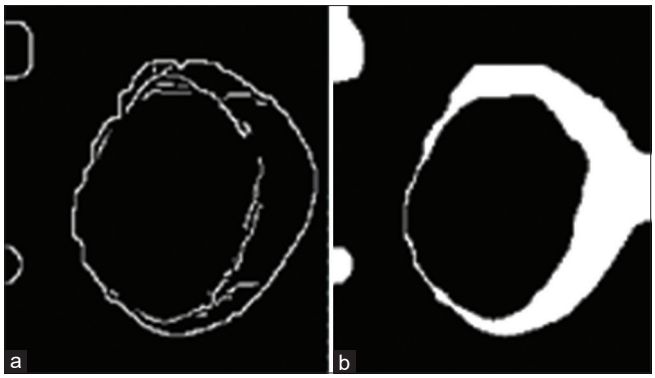

Figure 8: Effect of dilation operation. (a) Before and (b) after dilation

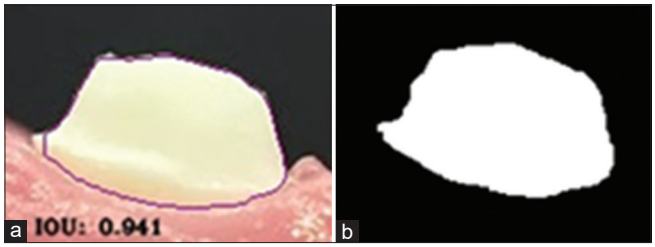

Figure 10: Contour segmentation in facial image. (a) Segmented contours by the proposed method, (b) segmented contour by expert

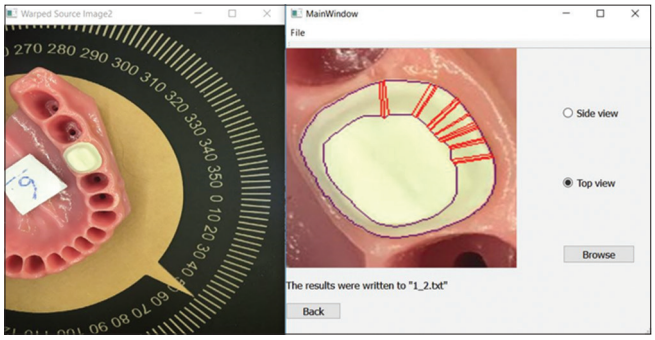

Figure 12: Crown preparation with differences higher than threshold

compared with the reference ranges to be assigned to the tooth or background. Figure 5 demonstrates a binary image after thresholding in HSV color domain.

Edge detection

To compute the tooth perimeter and area before and after tooth preparation, tooth edges should be segmented to lead to tooth contours. Here, the Canny edge detector is used with two thresholds T1 and T2.[22] If the pixel gradient is >T2, the pixel is marked as an edge, and for the case of being between T1 and T2, it is also considered an edge if the pixel is placed close to a current edge. Figure 6 shows the results of Canny edge detection applied to the selected ROI.

Morphologic operations

As indicated in Figure 6, extra edge pixels in the background are segmented by the edge detection method. This problem affects the following steps of processing.

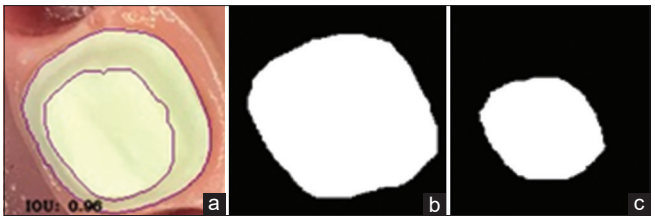

Figure 9: Contour segmentation in occlusal image. (a) Segmented contours by the proposed method, (b) exterior contour segmented by expert, and (c) interior contour segmented by expert

Figure 11: Corresponding points located in interior and exterior contours

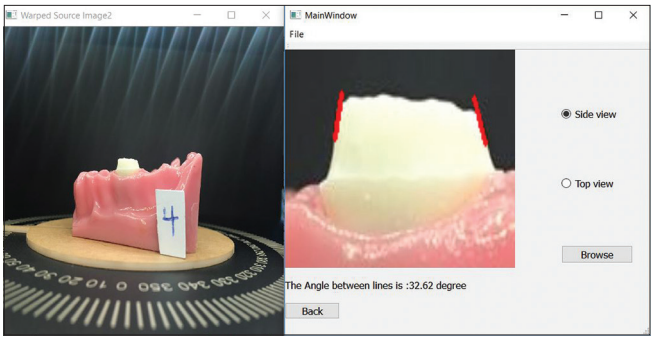

Figure 13: Crown preparation angle in facial image

To address this issue, morphology operations are used.[23] The main purpose of using such operations is to achieve convex and continuous contours. "Erosion" morphology operation is applied to images after the edge detection phase. This operation removes small white regions and creates continuous dark regions in the background. Figure 7 depicts the segmented edges of an ROI image with and without morphology operation.

For SecondImgs taken from the occlusal view, two contours are needed to be detected (the internal contour is the resulted contour after teeth preparation). In such case, "dilation" operation is applied after edge detection to find the internal counter. This operation connects the white regions. A sample image is demonstrated in Figure 8 to show the edges before and after the dilation operation.

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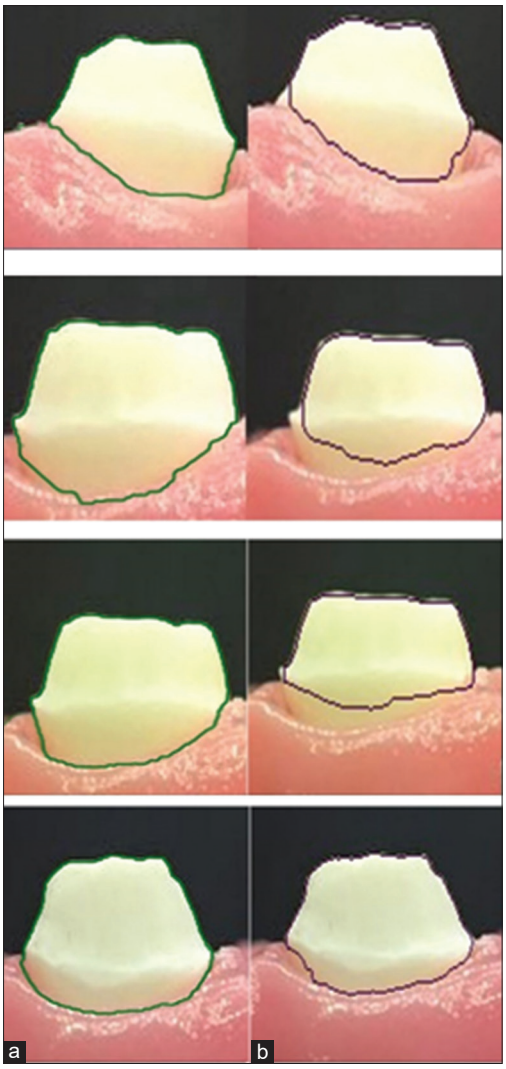

Figure 14: Segmented contours of four sample facial images by: (a) Expert and (b) the proposed method

Contour extraction

For occlusal images, the interior and exterior contours of the teeth are extracted. To find the exterior contour, different window sizes are considered for the structure element in morphology operations, which lead to extraction of different contours. The concaveness of the extracted contours is compared with a threshold, and a contour with the concaveness more than a threshold is selected. In cases that there is no contour with this condition, the contour with the lowest concaveness is selected. To find the interior contour, edges are detected by the Canny algorithm, followed by the dilation operation to connect discrete edges. The second maximum is selected among all extracted contours. If the concaveness of the selected contour is less than a threshold, it is selected as the final interior contour; otherwise, the contour with the minimum concaveness is selected. For facial images, the tooth perimeter should be considered by a similar method with occlusal images. The samples of the contours by proposed method and the ground truth by experts are depicted in Figures 9 and 10.

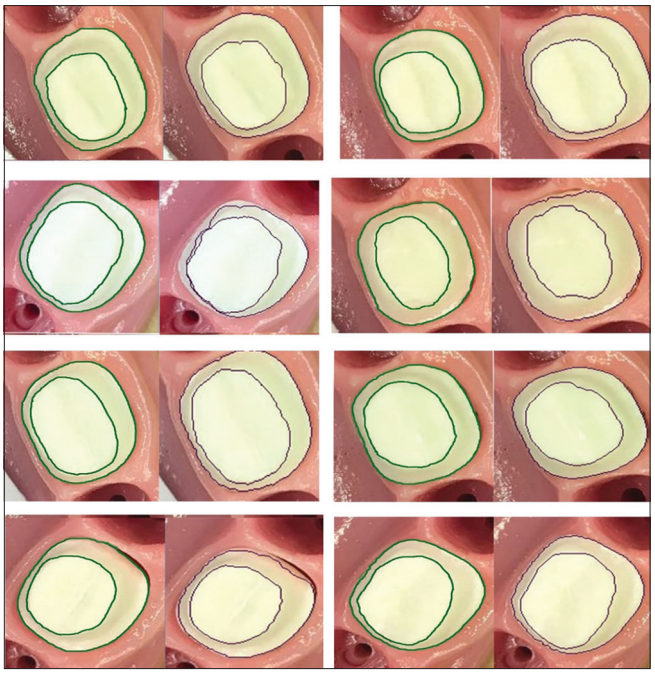

Figure 15: Segmented contours by the proposed method (left image) and expert (right image) in eight sample occlusal images

Computation of occlusal parameters (distances) for crown Preparation

The main objective of tooth image processing and contour extraction is to determine the irregular and regular parts of tooth preparation. After contour segmentation, the goodness of crown preparation can be quantitatively evaluated. For this purpose, all corresponding points located in the interior and exterior contours are considered counterclockwise [Figure 11].

It is expected that two interior and exterior contours have smooth changes and are in a similar distance. Namely, by assigning a threshold, contour differences more than a threshold are considered as an error [Figure 12, red colors].

Computation of facial parameters (angles) for crown preparation

Crown preparation angle is an important parameter which can be extracted from the facial images. Two lines on two sides of tooth region (after preparation) are considered to compute the crown preparation angle. To this end, first, the center of contours is determined, and then, the contour is divided into right and left sections. Two angles are then calculated for each section, which are expected to be in acceptable range and also to be symmetric enough [Figure 13].

Results

In this section, we discuss the proposed methods for parameter selection and the corresponding results.

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In the first step, HSV color space is used for tooth segmentation. To find the tooth color range, in each HSV color component, either the upper bound or lower bound is fixed, and then, another bound is changed to achieve the maximum accuracy for tooth segmentation. For the H component, the upper bound is fixed with 255 and the lower bound is selected among the quantities 5, 10, 15, and 20. Note that in this experiment, all tooth images are segmented correctly only in the lower bounds (5, 10, 15, and 20). Table 1 presents the accuracy of tooth segmentation in each tooth for different lower bounds of H. It is clear that the lower bound 10 (h_min = 10) achieves the best accuracy (0.89). Therefore, bound range from 10 to 255 is selected as the final range for component H. With a similar procedure, bound ranges from 0 to 93 and from 208 to 255 are selected for the components S and V, respectively. For components H and V, the upper bound 255 is fixed, whereas for component S, the lower bound 0 is fixed.

Erosion as a morphology operation is applied to images after the edge detection phase to remove small white regions and to create continuous dark regions in the background. The most important parameter in this operation is the window size, referred to as *stride*. The larger is the quantity of window size, the bigger white area around the tooth edge is removed (which may lead to elimination of correct tooth edge). For the window size, the upper bound is fixed to 40 and the lower bound is selected among the set 5, 10, 15, 20, 25, 30, 35. The accuracies for different window sizes are reported in Table 2. The window size 5 achieves the best average accuracy (0.89).

The window size for dilation is also explored for the occlusal and facial images. For dilation, the upper and lower bounds are considered as 12 and 5, respectively, with quantities 7 and 10 between them. Note that for window sizes 12 and less, all contours can be segmented correctly. This is the reason for selecting 12 as the upper bound. As it is clear from the reported accuracies for different window sizes in Table 3, window size of 7 is the best parameter for dilation.

The last parameter is the threshold value for the Canny edge detector. Canny uses two thresholds T_min and T_max for edge detection. Here, T_min is considered as 0 and T_max is selected from a range with a similar manner for the erosion and dilation parameters. Note that based on this experiment, Canny can correctly segment the edge of all images only in the interval 20–25 for T_max. Therefore, T_max is evaluated for quantities 20, 23, and 25, in which the highest accuracy (0.88) is observed in T_max = 25 [Table 4].

To show the effectiveness of the proposed method, the results are compared with ground truth labels by experts. The contours segmented by the proposed method and by experts in sample pairs of facial images are shown with cyan and green colors, respectively [Figure 14]. The segmentation results for sample pairs of occlusal images are also depicted in Figure 15.

To evaluate the performance of the proposed method in calculation of facial parameters (angles) for crown preparation, Table 5 reports the angle computed by the ground truth and the proposed method as well as the difference (signed error) and absolute difference (absolute error) between these angles for 12 images (images 10–21). The best correlation between the crown preparation angle in gold standard and the proposed method is achieved in image 10 with an absolute error of 2.5°, while image 21 is the worst case with an absolute error of 10.85. The mean absolute error for all images is 7.17.

The segmentation of desired region in facial images is also evaluated by the Intersection over Union (IOU) criterion.

Table 1: Accuracy of tooth segmentation for occlusal images with selection of different lower bounds for component H

Images number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Average
h_min=5	0.92	0.94	0.91	0.87	0.94	0.93	0.9	0.91	0.92	0.75	0.77	0.8	0.88	0.9	0.86	0.83	0.88	0.87	0.81	0.89	0.93	0.87
h_min=10	0.93	0.94	0.89	0.87	0.94	0.93	0.89	0.9	0.91	0.76	0.84	0.8	0.92	0.93	0.94	0.92	0.92	0.94	0.8	0.89	0.94	0.89
h_min=15	0.93	0.93	0.88	0.86	0.93	0.92	0.86	0.89	0.89	0.77	0.8	0.8	0.88	0.89	0.92	0.88	0.93	0.93	0.79	0.89	0.91	0.88
h_min=20	0.91	0.89	0.87	0.78	0.91	0.9	0.79	0.84	0.84	0.69	0.66	0.8	0.8	0.82	0.83	0.77	0.92	0.9	0.72	0.77	0.72	0.82

Table 2: Accuracy of tooth segmentation for occlusal images with selection of different window sizes for erosion operation

Images name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Average
Kerode=5	0.93	0.94	0.89	0.87	0.94	0.93	0.89	0.9	0.91	0.76	0.84	0.8	0.92	0.93	0.94	0.92	0.92	0.94	0.8	0.89	0.94	0.897
Kerode=10	0.93	0.94	0.89	0.87	0.94	0.92	0.89	0.9	0.91	0.76	0.84	0.8	0.92	0.93	0.94	0.91	0.91	0.94	0.8	0.89	0.94	0.894
Kerode=15	0.93	0.94	0.89	0.87	0.94	0.93	0.89	0.9	0.91	0.76	0.84	0.8	0.92	0.93	0.94	0.92	0.92	0.94	0.8	0.89	0.94	0.895
Kerode=20	0.93	0.94	0.89	0.87	0.94	0.92	0.89	0.9	0.91	0.76	0.83	0.79	0.92	0.92	0.93	0.9	0.91	0.94	0.8	0.89	0.94	0.891
Kerode=25	0.93	0.94	0.89	0.87	0.94	0.92	0.89	0.9	0.91	0.76	0.83	0.79	0.91	0.92	0.93	0.91	0.92	0.94	0.8	0.89	0.94	0.892
Kerode=30	0.93	0.94	0.89	0.87	0.94	0.92	0.89	0.9	0.91	0.76	0.82	0.79	0.9	0.91	0.92	0.89	0.9	0.94	0.8	0.88	0.93	0.887
Kerode=35	0.93	0.94	0.89	0.87	0.94	0.92	0.89	0.9	0.91	0.75	0.81	0.79	0.89	0.91	0.92	0.9	0.9	0.93	0.78	0.87	0.93	0.884

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Table 6 presents the IOU for all images (images 1–21). The best and worst performances are achieved in images 10 and 21 with IOUs of 0.76 and 0.94, respectively. The segmentation results of the proposed method have average an IOU of 0.89 in all images.

The occlusal parameters (distances) for crown preparation is another important output parameter of the proposed method. The internal and external contour segmentations are computed, and the IOU between automatically segmented regions with ground truth is reported in Table 7. It is concluded that the external contour with an averaged IUO of 0.93 is segmented more accurately than the internal contour with an averaged IUO of 0.88.

Discussion

Accurate and fair assessment of student works is usually considered as the most critical phase of education. In preclinical dental education, students need to receive consistent and accurate feedback from the faculty in order to achieve a higher level of performance before advancing to the clinics.[24] However, according to the attributors leading to disagreement over student works, including grading scale, rater calibration, and subjective influences, providing consistent feedback by the faculty is very difficult.[25] Valid and objective criteria would help resolve the grading crisis in dental education, which can be partly achieved by removing the human element from evaluation and developing objective evaluation methods.[26,27]

In our study, we have introduced a novel and convenient method for evaluating the quality of metal-ceramic tooth preparation by dental students. However, the innovated instrument has the potential to be planned for other crown materials by defining the cutoff points. This invention may improve the objective and repeatable judgment of students' work in preclinical settings. Moreover, this method does not require high-tech technologies such as scanner systems and is more user-friendly. The pre- and postpreparation photos can be taken by students' cellphones.

In the proposed method, the best results in segmentation of contours are achieved in cases with good imaging quality (appropriate light and imaging angle). However, our segmentation method is designed to be less sensitive to changes of such conditions. Furthermore, perfect segmentation is evident in specific regions of the image with an appropriate range of RGB color spaces. As shown in Figure 13, in some cases where these conditions have significant changes, the proposed method fails in correct segmentation. For example, if the color of gingiva is close to the dental color, the proposed method misleads the contour path and segments a smaller dental region. This scenario is also valid for both facial and occlusal images. For internal contours, when the edge of crown preparation is not clear, the contour will be segmented incorrectly and leads to a lower accuracy. Furthermore, if the side regions

Table 3: Accuracy of tooth segmentation for occlusal images with selection of different window sizes for dilation

Image name	1	2	3	4	5	6	7	8	9	Average
Kdilate=5	0.9	0.93	0.92	0.8	0.92	0.89	0.86	0.88	0.87	0.886
Kdilate=7	0.9	0.93	0.92	0.8	0.92	0.89	0.87	0.88	0.87	0.887
Kdilate=10	0.9	0.93	0.92	0.8	0.92	0.89	0.87	0.88	0.87	0.887
Kdilate=12	0.9	0.93	0.92	0.8	0.92	0.89	0.87	0.88	0.87	0.887

Table 4: Accuracy of segmentation for occlusal images with selection of different thresholds T_max for edge detection

Image name	1	2	3	4	5	6	7	8	9	Average
Thresh=20	0.9	0.93	0.89	0.8	0.92	0.89	0.87	0.88	0.87	0.883
Thresh=23	0.9	0.93	0.92	0.8	0.92	0.89	0.87	0.88	0.87	0.887
Thresh=25	0.9	0.93	0.92	0.8	0.92	0.89	0.87	0.88	0.89	0.889

Table 5: The angle of crown preparation computed by the proposed method and experts

Image number	21	20	19	18	17	16	15	14	13	12	11	10	Average
Ground truth angle	35.1	44.32	32.3	31.1	37.5	25.2	49.1	51	31.8	44.1	54.3	35.4	-
Computed angle	45.95	52.66	41.22	38.1	46.62	32.62	54.73	60.1	40.39	42.28	47.5	37.9	-
Signed error	−10.85	−8.34	−8.92	−7	−9.12	−7.42	−5.63	−9.1	−8.59	1.82	6.8	−2.5	-
Absolute error	10.85	8.34	8.92	7	9.12	7.42	5.63	9.1	8.59	1.82	6.8	2.5	7.17

Table 6: Intersection over Union for segmentation

Image number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Average
IOU	0.93	0.94	0.89	0.87	0.94	0.93	0.89	0.9	0.91	0.76	0.84	0.8	0.92	0.93	0.94	0.92	0.92	0.94	0.8	0.89	0.94	0.897

IOU: Intersection over Union

Table 7: Intersection over Union for internal and external contour segmentation

Image number	1	2	3	4	5	6	7	8	9	Average
External contour	0.96	0.95	0.86	0.94	0.96	0.97	0.91	0.92	0.95	0.93
Internal contour	0.9	0.93	0.92	0.8	0.92	0.89	0.87	0.88	0.87	0.887

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of the teeth are changed significantly, it is difficult to fit a single line and an error in angle computation appears.

Conclusions

In this research, a new package, including software and its prerequisite instruments, was proposed to help students in preclinical tooth preparation. For this purpose, images were taken from artificial teeth in different angles and directions before and after crown preparation and then were analyzed by the proposed methods to evaluate the quality and quantity of crown preparation. The proposed tooth image processing method had image registration, ROI segmentation, transformation to HSV color space, edge detection, morphology operation, and contour extraction abilities, which computed the amount and angle of crown preparation. Applying the proposed platform to a local tooth dataset showed a mean absolute error of 7.17 and a mean IOU of 0.89 in comparison to gold standard images segmented by the experts. Our method of evaluation seems totally a convenient aid to dental students to evaluate their work. However, before the application of this method as a part of dental education, the accuracy and validity of the outcomes should be tested against the faculty grading, a situation happening routinely in dental schools.

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Conflicts of interest

There are no conflicts of interest.

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