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Axial Tooth Contour Alteration Following Fixed Prosthodontic Treatment

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Abstract - *This study evaluated the effect of crown restoration on the tooth labial axial contour. The pre-treatment and post-treatment models of 13 patients who underwent complex fixed prosthodontic treatment were obtained. All the models were converted to virtual models. Each post-treatment model was overlapped on the corresponding pre-treatment model to evaluate the contour alteration of the clinical crown. The contour of the crowned teeth significantly increased following the crown restoration treatment. The increase of the contour was directly proportional to the distance from the gingival margin. The anterior teeth had a significantly greater contour increase than the posterior teeth.*

KEY WORDS: Crown contour, overcontouring, image registration, microCT

INTRODUCTION

Prosthodontic treatment is frequently indicated to restore compromised, discoloured and unaesthetic teeth. Among the objectives of prosthodontic treatment is the preservation of dental and periodontal health, minimizing of bacterial biofilm formation and allowing for efficient cleaning. In the process of the treatment, a specific amount of tooth structure on different surfaces should be removed to provide sufficient space for the crown restoration. This space is necessary to ensure that there is enough bulk of the prosthesis material for aesthetics, mechanical durability and adequate contour of the crown[1,2]. It has been speculated that, the ideal prosthesis contour should follow the contour of the remaining tooth structure without prominent convexity. This feature will ensure that the prosthesis blends harmoniously with the adjacent teeth[2].

After observing natural teeth, the portion of the axial tooth contour that extends from the base of the gingival sulcus to the supragingival aspect should exhibit a straight profile[3]. Such a contour will render the tooth more cleansable at the critical regions[2]. On the other hand, excessive overcontouring of the gingival third of the crown can alter the biologic relationship between the tooth and the periodontium, impede adequate oral health cleaning and contribute to gingival inflammation[4-6]. However, it is not uncommon for tooth contour to be altered following prosthetic treatment[7,8] and, in many instances, altering the tooth contour may be desirable and is perceived as an objective of the treatment.

In the literature, three concepts for establishing axial tooth contour were prescribed: duplication of original tooth anatomy, undercontouring, and overcontouring. Preserving the original tooth contour is thought to be biocompatible with its surrounding environment[3,7]. The drawback of this concept is that the tooth contour will not be modified following the treatment. Undercontouring the crowns is another method based on the clinical observation that the gingival tissues will likely to be maintained as they are more self-cleansible[2,9,10]. However, this method is impractical as it could affect the appearance, crown thickness and preparation invasiveness[9]. This could explain why this method is not favoured. The third method is contouring the restoration according to pre-treatment planning in the form of diagnostic wax-up[11,12]. The rationale behind this method is the tooth preparation is dictated by the final volume of crown restoration rather than the existing tooth contour. Therefore, there is a tendency for this method to be more conservative, but could result in overcontoured surfaces.

The aims of this study are to evaluate the effect of crown restoration treatment on the labial axial contour of teeth and to investigate the implications of dentition variables on the final crown contour. The evaluated variables were inter-arch location (maxillary vs. mandibular arches), intra-arch location (anterior vs. posterior location), tooth category (incisors, canines, premolars and molars) and tooth surface location (mid-tooth vs. line angle).

MATERIALS AND METHODS

A human research ethics approval was obtained from the Human Research Ethics Committee of the University of Western Australia (RA/44/1/5079). Models of 13 patients receiving multiple crowns prosthetic treatment were collected. A total of 173 teeth were restored with single crown fixed prosthodontic treatment. Patients requiring multiple crown restorations were selected, as the definitive crown contour will be less dependent on the contours of the adjacent non-restored teeth. For all the teeth, a form of diagnostic wax-up was completed. Before proceeding to the definitive crown restorations, each patient had to approve the diagnostic wax-up and the subsequent provisional restorations. Thus, all the contour alterations were planned to satisfy patient's aesthetic demands. All the crown restorations were porcelain-fused to metal crowns. None of the

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included teeth received gingival re-contouring treatment or orthodontic treatment. The treatments were provided at the Oral Health Centre of Western Australia. One clinician was responsible for approving the diagnostic wax-ups and delivering the definitive treatment. The crown restorations were fabricated by several technicians.

Pre-treatment models

For each patient, maxillary and mandibular impressions were taken by irreversible hydrocolloid impression material (Alginate, GC America, IL, USA). The impressions were poured by dental stone (Buff Stone, Adelaide Moulding & Casting Supplies, South Australia, Australia) (Figure 1A). The models were scanned by a Micro-CT scanner (SkyScan, Bruker microCT, Kontich, Belgium) (12 µm resolution, 360° scanning, 70 KV source voltage, 1.0 mm Al filtration). The advantage of Micro-CT scanning is the ability to produce an accurate image that exhibits a dimensional error of 0.1%[13]. Virtual 3D Stereolithography (STL) images were constructed from the Digital Imaging and Communication Medicine (DICOM) images with the aid of a DICOM viewing program (CTvox, Bruker microCT, Kontich, Belgium) (Figure 1B).

Post-treatment models

Following the fixed prostheses insertion, the patients were placed on a regular review and recall regime. The first review appointment was set at one to four post-treatment weeks in which additional alginate impressions were obtained (Figure 1C). Following the pouring of the impressions, the models were scanned by the Micro-CT scanner. Similarly to the pre-treatment models, virtual STL images were constructed (Figure 1D).

Analysis

For the direct comparison between the pre-treatment and post-treatment models, all the models were remeshed with a density of 0.1 mm. All the measurements were completed digitally. In order to compare the tooth contour of pre-treatment and post-treatment models, the models of each arch were overlapped. The overlapping of models involves the automatic alignment of two 3D images to ensure exact 3D orientation[14,15]. The overlapping process was performed by a 3D rendering software package (Geomagic Studio, Raindrop Geomagic Inc., Research Triangle Park, NC, USA) through two sequential steps: (1) point-to-point registration, and (2) global registration. The point-to-point registration determines the initial approximate orientation of the pre-treatment and the post-treatment model images by manually locating at least three common landmarks. The points were selected on unaltered portions of the models. The global registration is based on the Iterative Closest Point algorithm[14], and it aims to align the meshes according to the best-fit principle (Figure 2). Accurate overlapping of the unaltered surfaces was verified by a heat map.

Following the image overlapping, on each crowned tooth, three virtual planes were located on the labial aspect: (1) mid-tooth, (2) mesial line angle, and (3) distal line angle (Figure 3A). Only the labial surfaces were evaluated as it is the commonly altered surface for aesthetic purposes. In addition, the lingual surface of many crowns was located supragingivally which does not critically alter the tooth contour. Therefore, a total of 519 sites were evaluated (n = 519). The discrepancy between the models was measured in the gingival 3 mm of the clinical crown. This dimension was selected as it tends to exhibit the greatest convexity on the labial surfaces[2,3]. Five levels were selected in relation to the gingival margin: 0.0, 0.5, 1.0, 2.0, and 3.0 mm from the

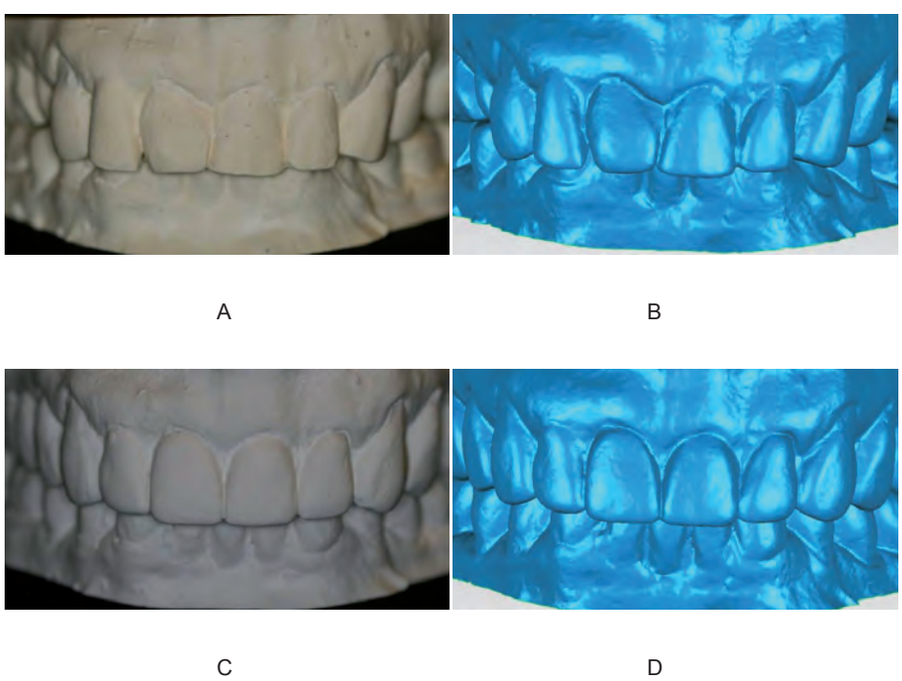

Figure 1. *The actual (A) and virtual (B) pre-treatment models. The actual (C) and virtual (D) post-treatment models.*

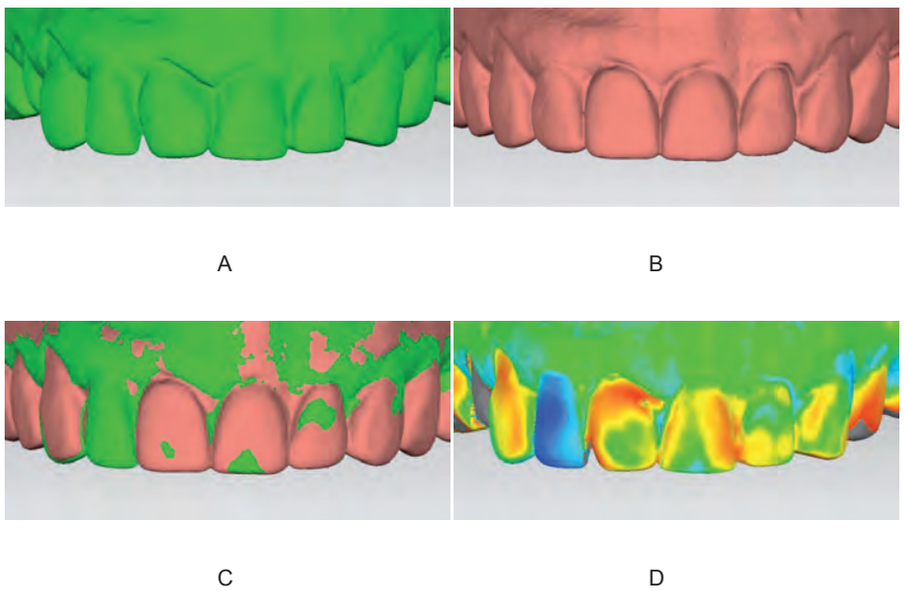

Figure 2. *Virtual overlapping of the pre-treatment (A) and post-treatment (B) models.The overlaped models according to the common surfaces (C).The heat map on the pre-treatment model confirmed the accurate overalaping (D).The green colour indicates a close fit (unaltered surfaces), while the hot colours outline the positive distances (model enlargement) and the cold colours outline the negative distances (model reduction).*

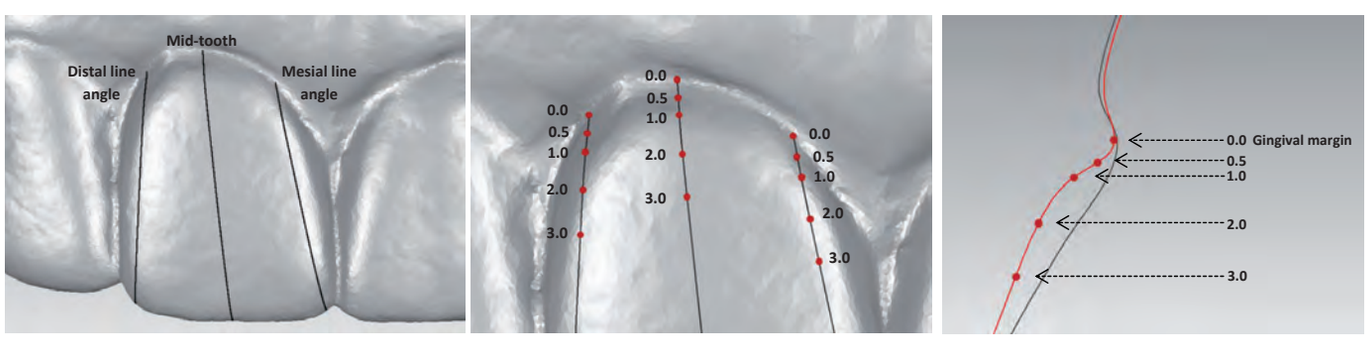

Figure 3. *(A) An image illustrating the extracted three labial planes. (B) a magnified image outlining the five vertical measurments on each plane. (C) a cross sectional view of an extracted plane on the pre-treatment model (black line) and the correspnding plane on the post-treatment model (red line).*

gingival margin (Figure 3B and 3C). For each location, a digital point was located on the pre-treatment model and the corresponding location of the post-treatment model. Subsequently, the distance between the points was measured. A minimal magnitude indicates a close match between the models, while a great magnitude indicates significant surface alteration following the prosthetic treatment. Positive values indicate that the crown surface is greater than the tooth contour while negative values indicate that the crown surface is less than the tooth contour.

Statistical analysis

At each level, the average contour alteration and standard error was calculated. The effects of the following dentition variables on tooth contour were evaluated: inter-arch location (maxillary vs. mandibular arches) and intra-arch location (anterior vs. posterior location). Further, the effect of the following tooth variables was investigated: tooth category (incisors, canines, premolars and molars) and tooth surface location (mid-tooth vs. line angle). The normality of the data was confirmed by Kolmogorov-Smirnov test. The interaction between measurement level, inter-arch location and intra-arch location was evaluated by three-way ANOVA test and Tukey post hoc test (p value = 0.05). The same test was implemented to evaluate the interaction between measurement level, tooth category and tooth surface location. The statistical analyses were conducted by SPSS software package (IBM SPSS Statistics, version 22, SPSS Inc., Chicago, IL, USA). In addition, the contour alterations for each tooth category were plotted in bar diagrams.

RESULTS

Overall, the post-treatment models showed a wider labial tooth contour than the pre-treatment models. The more supragingival the measurements were, the greater the contour alteration magnitude. . From 0.0 mm to 3.0 mm levels, the mean values (standard error) were 0.05 mm (0.006 mm), 0.14 mm (0.011 mm), 0.19 mm (0.013 mm), 0.28 mm (0.016 mm) and 0.34 mm (0.019 mm) respectively. The difference between all the levels was greatly significant.

Inter-arch location (maxillary vs. mandibular teeth)

Table 1 summarizes the outcome for the maxillary and mandibular teeth. For the two arches, there is a significant difference between the levels of measurements. After comparing the two arches, at 0.5 mm level, the mandibular teeth had significantly less contour increase than maxillary teeth, while at 3.0 mm level, the mandibular teeth had significantly greater contour increase than maxillary teeth. At the other levels, there was no significant difference between the two arches.

Intra-arch location (anterior vs. posterior)

Overall, regardless of the arch, the anterior teeth had a significantly greater contour increase than the posterior teeth (Table 2). The only exception was for 0.0 mm level, where the anterior and posterior teeth contours were similar. For the anterior teeth, there was a difference between all the levels of measurements. While for posterior teeth, there was insignificant difference between levels 0.0 mm and 0.5 mm, 0.5 mm and 1.0 mm, and 2.0 mm and 3.0 mm.

Table 3 illustrates the interaction between anterior and posterior teeth for the different arches. After comparing the maxillary anterior teeth with the posterior teeth, at levels 0.5 mm, 1.0 mm and 2.0 mm the anterior teeth had significantly more contour increase than the posterior teeth. For the mandibular teeth, the anterior teeth had a significantly greater contour increase than posterior teeth for all the levels except at 0.0 mm level.

After comparing the anterior teeth of the maxillae with the anterior teeth of the mandibles, there was a significant difference at levels 0.5 mm and 1.0 mm (more for maxillary teeth). However, the posterior teeth comparison revealed no significant difference between the maxillary and mandibular teeth at any level.

Tooth variables (tooth category and tooth surface location)

It is clear that all the teeth had experienced an increase of tooth contour in each level following the prosthodontic treatment. However, the tooth contour alterations differed markedly between teeth (Figure 4). The incisors were the most affected teeth by the crown restorations, followed by the canines and premolars. The contour of the molars was the least affected by the crowning.

After comparing the contours of the different teeth at each level, at 0.0 mm level, only the incisors had significantly greater contour than molars, while for the rest of the teeth, there was no significant difference. At 0.5 mm level, the molars had significantly less contour increase than all teeth category, while the difference between the other teeth was insignificant. For the 1.0 mm level, the molars had

Table 1. The mean and standard error (SE) for the maxillary and mandibular teeth contour alterations after the crown treatment

Level (mm)	*Maxillary teeth (mm) (n = 300)*		*Mandibular teeth (mm) (n = 219)*		*Difference*
	Mean	*SE*	*Mean*	*SE*	
0.0	0.07	0.009	0.03	0.008	Insignificant
0.5	0.16	0.014	0.10	0.015	Significant
1.0	0.21	0.017	0.15	0.018	Insignificant
2.0	0.28	0.021	0.28	0.025	Insignificant
3.0	0.32	0.024	0.38	0.030	Significant

Table 2. The mean and standard error (SE) for the anterior and posterior teeth contour alterations after the crown treatment

Level (mm)	*Anterior teeth (mm) (n = 276)*		*Posterior teeth (mm) (n = 243)*		*Difference*
	Mean	SE	Mean	SE	
0.0	0.07	0.008	0.03	0.010	Insignificant
0.5	0.18	0.014	0.09	0.015	Significant
1.0	0.25	0.016	0.12	0.019	Significant
2.0	0.35	0.021	0.20	0.023	Significant
3.0	0.41	0.026	0.27	0.026	Significant

Table 3. Crown contour alterations mean and standard error (SE) for the anterior maxillary and mandibular teeth, and posterior maxillary and mandibular teeth after the crown treatment

Level (mm)	*Anterior teeth*				*Posterior teeth*				*Anterior teeth vs. posterior teeth comparison*	
	Maxillary teeth (mm) (n = 162)		*Mandibular teeth (mm) (n = 114)*	*Difference*	*Maxillary teeth (mm) (n = 138)*		*Mandibular teeth (mm) (n = 105)*	*Difference*	*Maxillary teeth*	*Mandibular teeth*
	Mean	*SE*	*Mean*	*SE*		*Mean*	*SE*	*Mean*	*SE*			
0.0	0.09	0.012	0.03	0.011	Insignificant	0.04	0.014	0.01	0.013	Insignificant	Insignificant	Insignificant
0.5	0.20	0.020	0.10	0.021	Significant	0.11	0.021	0.05	0.022	Insignificant	Significant	Significant
1.0	0.27	0.022	0.16	0.025	Significant	0.14	0.026	0.09	0.026	Insignificant	Significant	Significant
2.0	0.34	0.027	0.28	0.035	Insignificant	0.22	0.033	0.18	0.032	Insignificant	Significant	Significant
3.0	0.35	0.031	0.38	0.039	Insignificant	0.28	0.037	0.27	0.037	Insignificant	Insignificant	Significant

significantly less contour increase than all the teeth. In addition, the incisors had significantly greater increase than premolars. At 2.0 mm level, the incisors had significantly greater contour increase than the rest of the teeth, and the molars had significantly less contour increase than all the teeth. At 3.0 mm level, the molars had significantly less contour increase than all the teeth. In addition, the incisors had greater contour increase than canines.

Figure 5 (A-D) illustrates the contour alterations of each tooth category for the mid-tooth and line angle locations for the two arches. Regardless of the arch and the tooth category, the graphs showed a consistent pattern of contour increase with the increasing level of measurement.

For the maxilla (Figure 5A and 5B), all the teeth were minimally affected at the gingival margin level (0.0 mm level) at all the locations (less than 0.1 mm alterations). For the incisors, a slightly greater contour increase was observed at the line angles compared with the middle of the tooth. The canines, however, showed the opposite outcome. The premolars showed similar effects at the middle and line angle locations. The molars were more affected at the line angles than at the middle of the teeth. Statistically, however, there was no difference between the middle and line angle locations for any tooth category.

For the mandible (Figure 5C and 5D), the teeth were less affected than for the maxilla at the gingival margin level (0.05 mm alterations or less). However, no statistical difference was observed. The incisors were generally the most affected and the magnitude of discrepancies was similar for the two surface locations on the teeth. The canines were more affected at the line angle aspect than at the mid-tooth aspect. The premolars and molars generally exhibited similar discrepancy patterns. None of the teeth showed a statistically significant difference between the mid-tooth and line angle locations.

DISCUSSION

This descriptive study indicates that the crowned teeth experienced an increase in the labial contour following provision of crowns. Further, the increase of the labial contour shows a linear relationship to the distance from the gingival margin. This observation and the obtained magnitude of contour increase are in accordance with several studies that evaluated the impact of fixed prosthesis on tooth contour[7,8]. With the aid of contact scanner and image registration, Meijering et al. found the dimensions of the veneered teeth were unintentionally increased, resulting in overcontoured labial surfaces[8]. In the same study, the increase in the labial contour was in the range of 0.33 mm to 0.59 mm. Further, they found that the increase tends to be greater incisally. Similarly, a contact profilometer study by Vasconcelos et al. found the contour of all the veneered teeth significantly increased from the original contour by 0.37 mm to 0.44 mm. They also found that the increase of the contour was directly related to the distance from the gingival margin[7]. They indicated that there is a tendency for the manufacturing technician to produce overcontoured restorations. From the technical perspective, producing overcontoured restorations might be desirable since it will facilitate tooth shape improvement, provide more material space for natural shade matching, and increase restoration bulk and durability[1].

It has been postulated that an enlarged tooth contour will inhibit adequate home care and hinder self-cleansing abilities, which will inevitably contribute to increased gingival inflammation, periodontal complications and subsequent caries[4-6]. From an anatomical perspective, Burch et al. recommended that the maximal convexity should occur on the gingival third of the crown of the restored tooth and should not exceed 0.5 mm[16]. In a dog study, Perel increased the contour on the labial aspect

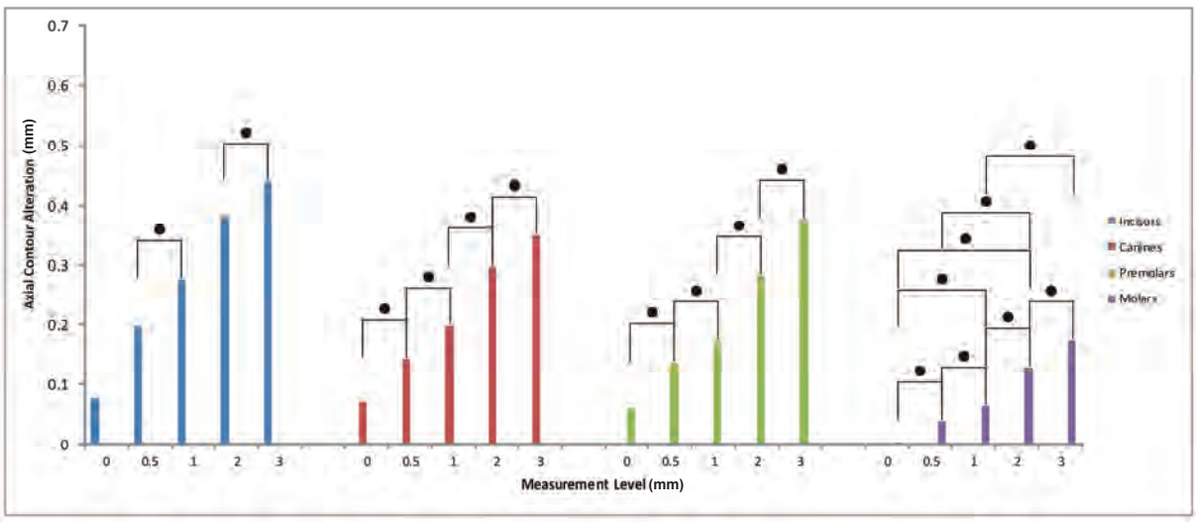

Figure 4. *Bar diagram illustrating the contour alteration of each tooth category. (●) Indicates lack of singificant difference between the levels of measurements.*

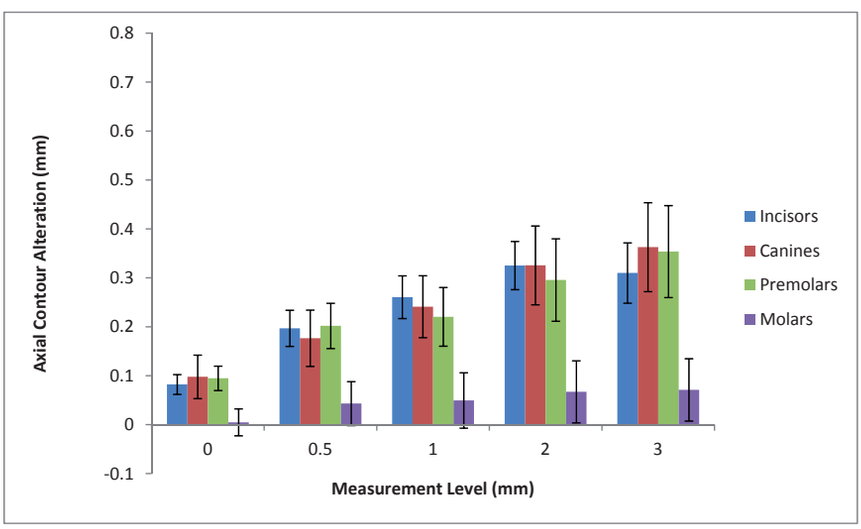

Figure 5. A

A

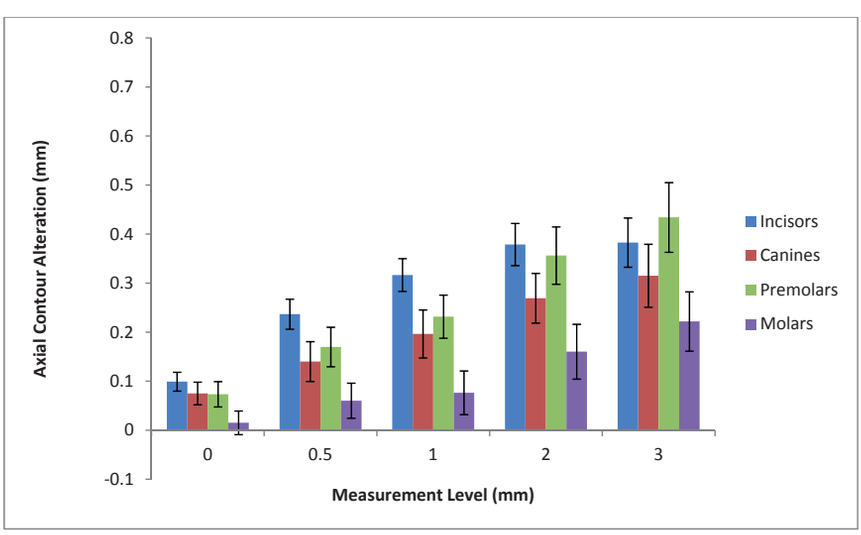

Figure 5. B

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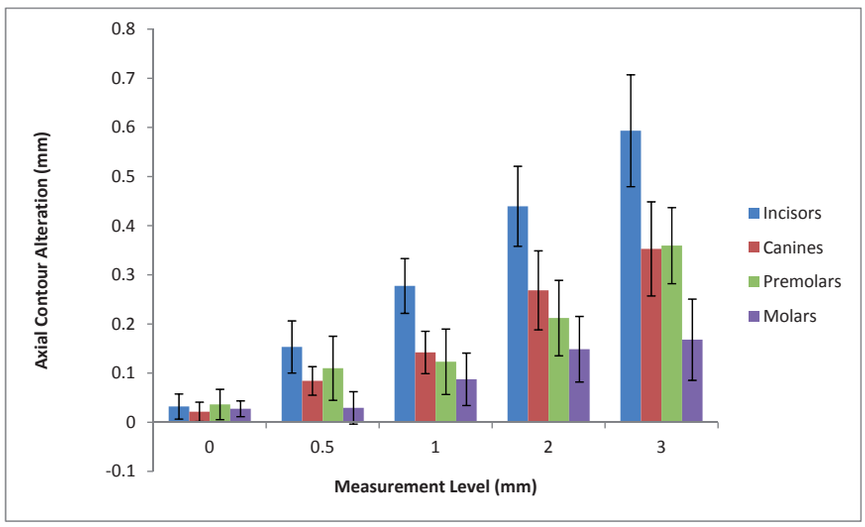

Figure 5. C C

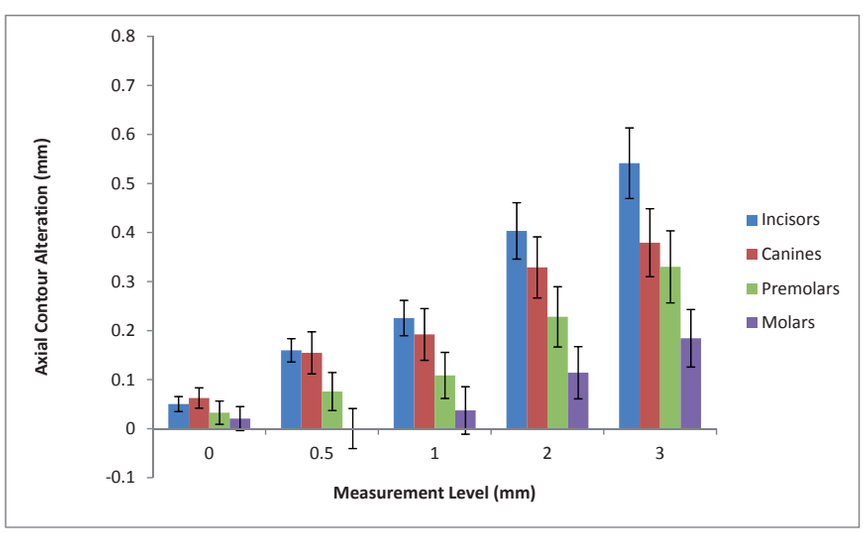

Figure 5. D D

Figure 5. *Bar diagrams illustrating the contour alteration of each tooth category for the maxillary mid-tooth region (A), maxillary line angle region (B), mandibular mid-tooth region (C) and mandibular line angle region (D).*

0.5 mm above the gingival margin. The overcontoured restorations resulted in gingival inflammation[10]. However, this outcome was refuted by another dog study which found that as long as professional oral hygiene is properly executed, periodontal health is minimally influenced by the overcontoured crowns[17]. A follow-up study by the same investigators confirmed that the microbial composition was slightly affected by the overcontoured crown[18]. In a human split-mouth study, Ehlrich and Hochman provided up to 1 mm overcontoured crowns on one side and undercontoured crowns on the other side. After a period of 4 months, the periodontal status between the two sides was found to be similar[19]. Likewise, Sundh and Kohler[20], on 6 patients, tried three experimental crowns with different emergence profiles. After one week of normal oral hygiene practice, all the experimental crowns exhibited similar plaque quantity and quality. Further, the plaque quality was similar to the contralateral control teeth. The conclusion was that an increased emergence profile did not contribute to increased plaque accumulation. Therefore, it appears that as long as adequate oral hygiene can be maintained, reasonable overcontouring (up to 1 mm) will not contribute to periodontal complications.

The linear increase of the crowned tooth contour coronally indicates that contour alteration will most likely blend smoothly with the unaltered tooth surface. Since all the teeth had the least measurement at the gingival margin level (less than 0.1 mm), this increase might not be significant enough to interfere with the gingival contour or prevent adequate home care. Further, the gradual increase for the area of 3.0 mm supraginigvally most likely is beneficial, as it will not result in an abrupt contour increase, which may protect the bacterial biofilm. In this study, although the maximal contour increase occurred at level 3.0 mm, the magnitude of increase was less than 1.0 mm for all

the teeth. Such a magnitude of increase is less than what has been recommended to be the maximal alteration[19]. In addition, following crown treatment, the development of caries and gingival complications cannot be attributed only to the crown contour. Instead, the quality of the tooth margin, marginal integrity and regular patient home care might be more critical[21]. Nevertheless, more long term clinical studies are required to evaluate the impact of prosthetically-increased tooth contour.

Although all the teeth experienced contour enlargement, the anterior teeth were more vulnerable to the increase of contour than posterior teeth labially. This could be attributed to the greater aesthetic demand and the attempt to improve the tooth dimensions[11]. This has been confirmed by Ehlrich and Hochman who reported that 3 out of 4 participants preferred the overcontoured crowns over the undercontoured crowns[19]. Slight over-contouring of anterior teeth might be advantageous from the conservative perspective. Since the anterior teeth have less tooth structure available for the preparation than posterior teeth, there is a clinical preference to minimize the amount of tooth reduction[1]. For example, the cervical dentine thickness for the mandibular incisors in some regions is about 1.5 mm[22]. Therefore, a shoulder or chamfer of 1 mm width will sacrifice a major proportion of the remaining teeth and can lead to pulpal complications. Alternatively, underpreparation and slight overcontouring of the crown restoration might be a conservative approach. Consequently, diagnostic wax-up is strongly recommended in situations where significant tooth contour alteration is to take place. A template constructed according to the diagnostic wax up can be utilized to ensure the preparation is adequate for the final crown volume, rather than the initial tooth contour[11,12]. From the biological aspect, maintaining the cleanliness of the anterior teeth is very feasible. Therefore, it could be envisaged that slightly overcontoured anterior teeth will not hinder regular patient home care, and the advantages of reasonable overcontouring of anterior crown restorations exceeds the potential risk.

On the other hand, it is advantageous for the posterior teeth, especially molars, to have less contour increase. From the aesthetic perspective, since most of the posterior teeth are not in the aesthetic zone, there is minimal merit in significantly altering their labial contour. Further, there will be no clinical advantage of increasing the contour of the posterior teeth to realign them[23]. In addition, for posterior teeth, it is more important not to have a prominent convexity as they are more difficult to clean than anterior teeth. The importance of a straight profile for posterior teeth is even greater in situations where the furcation is exposed[2].

A critical area that needs evaluation is the impact of crowning teeth on the interproximal contour. Due to the methodology applied, it was impossible to evaluate the interproximal surfaces in the current study. There are some advantages of increasing the interproximal contour for teeth with gingival recession such as the reduction of the black triangle, minimizing the impaction of food, and supporting the interdental papilla[24].

This study is distinguished from the previous studies that evaluated the effect of contour alteration by obtaining all the measurements digitally. Over the conventional measurements, digital measurement has the advantages of being convenient and more consistent. In fact, several authors reported that virtual measurements have the tendency to be more consistent than conventional microscopic measurements[25,26]. The accuracy and consistency of measurements were attributed to the possibility of magnifying the images and consistently locating the points of interest. This has the potential to reduce operator-induced errors. Nevertheless, the applied methodology introduces inevitable dimensional inaccuracies. The clinical impression procedure and dental stone pouring are associated with accumulated errors in the form of shrinkage and expansion [27]. This accumulated error was reported to be about 0.20 mm by earlier investigations [14,15]. In addition, it is very difficult to generalize the outcome of this study, as it only includes few patients. Further, as each patient of in this study had received several crowns, the observed contour increase could be partly due to generalized contour alteration of the dentition. The effect of contour alteration due to single tooth crown restoration should be evaluated in a separate investigation.

CONCLUSIONS

Within the limitations of this study, it could be concluded that:

- The axial contour of all the treated teeth with crowns was increased. This increase was clearly proportional to the distance from the gingival margin.
- The anterior teeth were more affected by the increase of the contour than the posterior teeth.
- Although the observed magnitude of labial contour increase was below the maximal contour that may affect gingival health, the long term impact of the altered contour should be evaluated.

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ADDRESS FOR CORRESPONDENCE

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