Effect of Chairside CAD/CAM Restoration Type on Marginal Fit Accuracy: A Comparison of Crown, Inlay and Onlay Restorations

Keywords

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ABSTRACT

Chairside CAD/CAM is a convenient approach for fabricating dental restorations. However, the effect of CAD/CAM restoration type on marginal fit accuracy has not been fully investigated. This study evaluated of the marginal fit accuracy of 3 chairside CAD/CAM restoration types (crown, inlay and onlay) using CEREC Bluecam (BC) and CEREC Omnicam (OC) scanners. Three artificial maxillary first molars received crown, inlay and onlay preparations. A total of 10 CAD/CAM ceramic restorations were produced for each tooth by each intraoral scanner. The marginal gap was measured along the preparation margin. For the BC, all the restorations had similar marginal gaps (crowns = 113.9 µm; inlays = 120.9 µm; onlays = 132.5 µm) ($p = 0.20$), while for the OC, the crowns (72.2 µm) and the inlays (74.9 µm) exhibited better marginal fit than the onlays (96.4 µm) ($p = 0.003$). For every restoration type, the OC provided a superior outcome compared with the BC. Therefore, the restoration type influenced the marginal gap, where the crowns tended to have the least marginal gap while the onlays had the greatest marginal gap. The newer scanner (OC) of the same manufacturer was more accurate than the older scanner (BC).

INTRODUCTION

Chairside CAD/CAM workflow has the advantages of convenience, practicality, reduction of clinical sessions, and reduction of reliance on dental technicians.[1-4] Several studies indicated that chairside CAD/CAM workflow is a reasonable alternative to conventional workflows that involve traditional impressions and laboratory restoration fabrications.[1-12] However, CAD/CAM technologies, such as scanners, software programs, and manufacturing units, are continuously evolving.[1] Of interest to the clinicians, the intraoral scanner receives the greatest attention, as it has a direct effect on the clinical aspect of CAD/CAM and the ease of digital impressions. While it is expected that manufacturing companies need to upgrade their systems, such process may have an economical burden on the clinicians relying on CAD/CAM dentistry. Currently, there are no clear guidelines for the clinicians on when it is necessary to upgrade their chairside CAD/CAM units. More importantly, it is worthy to investigate if the newer scanning systems will improve the clinical outcome in a way that justifies the upgrade.

In the appraisal of CAD/CAM systems, restoration fit is a frequently used measure of reliability of any system. Accurate fit of indirect restorations is necessary to ensure its longevity. Restoration misfit can lead to cement deterioration, biofilm formation, caries, gingival inflammation, sensitivity, marginal discoloration,[13-16] occlusal errors and restoration dislodgement.[1,2] A marginal gap in the range of 100 µm to 200 µm has been reported to occur for restorations by chairside CAD/CAM workflow.[5-12,17,18] This level of misfit has been attributed to the different steps of chairside CAD/CAM fabrication such as scanning, virtual margin determination, modelling, and milling. One of the factors that has not been properly investigated and may implicate the fit of the restoration is the type of CAD/CAM restoration.[2] While there are general recommendations on the features of tooth preparation that can improve restoration fit,[19] the impacts of different restoration types and their tooth preparation designs on restoration fit are not well explored.[2] Therefore, the aim of this study was to evaluate the marginal fit accuracy of different types of chairside CAD/CAM restorations (crown, inlay and onlay) using 2 scanning systems by the same CAD/CAM manufacturer (CEREC Bluecam and CEREC Omnicam). These 2 systems were chosen because they represented 2 generations of intraoral scanners the same manufacturer. The null hypotheses are there is no effect of chairside CAD/CAM restoration type on the marginal fit accuracy, and there is no effect of the different scanners by the same CAD/CAM manufacturer.

MATERIALS AND METHODS

Three maxillary right first molars of the Nissin teaching model (Nissin Dental Products Inc., Kyoto, Japan) were prepared to receive crown, inlay, and onlay restorations by an experienced clinician. Tooth preparations were performed according to the recommended principles to optimize the outcome of chairside CAD/CAM restorations.[19] The crown preparation *(Figure 1A)* had a well-defined 1 mm circumferential rounded shoulder margin that was 1 mm supragingival. The occlusal surface was reduced by 2 mm, all the line angles were rounded, and an occlusal taper of 10-15° degrees was established. The inlay preparation *(Figure 1B)* had a mesio-occlusal outline extending two thirds of the occlusal surface with a minimum occlusal reduction of 2 mm. A 1 mm wide mesial box was incorporated with a margin located 1 mm supragingivally. The onlay preparation *(Figure 1C)* had a cuspal reduction of 2 mm parallel to the occlusal anatomy, and a central isthmus reduction of 3 mm occlusally and 2 mm buccolingually. Mesial and distal boxes were incorporated with the onlay preparation similar to the inlay box. All the internal line angles of the inlay and onlay preparations were rounded, and the internal wall had a divergence of 10-15°.

Two intraoral scanners from the same manufacturer (CEREC, Sirona, Bensheim, Germany) were used in the study, CEREC Bluecam (BC) and CEREC Omnicam (OC). Despite the differences in the intraoral scanners, the software and milling unit

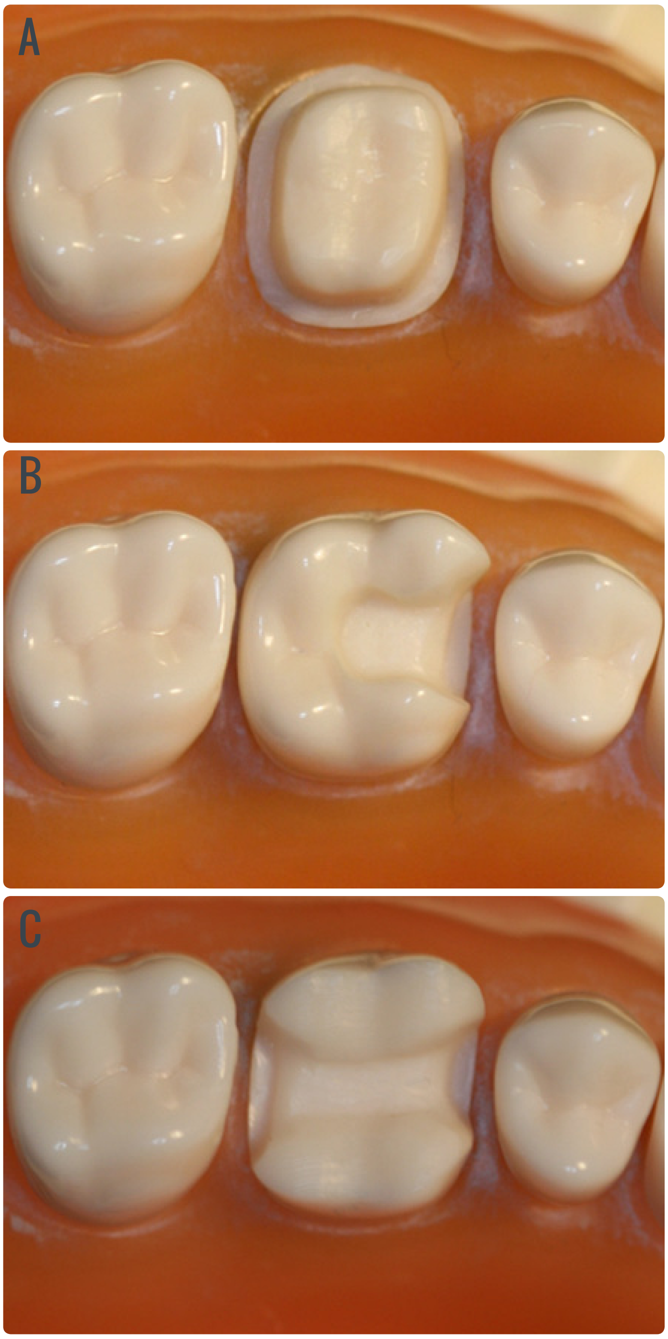

Figure 1: Images of crown (A), inlay (B) and onlay (C)

were similar for all restorations. For each prepared tooth in the maxillary arch, the right quadrant was scanned. This involved the 1st premolar till 2nd molar of the right side. The opposing mandibular quadrant was scanned, followed by scanning the buccal side of the articulated models. Prior to scanning, the intraoral scanning units were calibrated. The scanning procedure with each unit was completed in accordance with the manufacturer's recommended scanning protocols. For the BC scanning, the relevant teeth were sprayed with CEREC Optispray (CEREC, Sirona, Bensheim, Germany). Since the BC is an older scanner, it executed the scanning via multiple snap images acquisition of the powdered surfaces. For the OC, the scanning was conducted without spraying, and was distinguished by continuous automated imaging of surfaces without powder application. Each scanner was used to scan every prepared tooth 10 times. Subsequently, each scanned image was used to design and fabricate a restoration, resulting in a total of 10 crowns, 10 inlays and 10 onlays per scanner. A single CAD software (inLab CAD SW 16, CEREC, Sirona, Bensheim, Germany) was used to design every restoration. Restoration margins were manually traced on the preparation, after which the external surface of whole restoration was virtually determined. For all restorations, a virtual die spacer of 80 µm was added up to 0.5 mm from the margin. The finished restoration design was then transferred from the CAD software to the CAM milling unit (CEREC MC XL, Sirona, Bensheim, Germany), and the restorations were milled from feldspathic ceramic blocks (Vita MKII, VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Säckingen, Germany). This material was chosen to avoid any further post-milling treatment that may influence the accuracy of the produced restoration. After the milling, the restoration was separated from the base of the ingot and mechanically polished. None of the produced restorations received any adjustment at the internal surfaces.

The prepared teeth were detached from the maxillary arch model and the cavosurface margins of the prepared teeth were marked at 1 mm increments along the whole margin with a permanent black marker. Each restoration was seated onto the respective prepared tooth with light body polyvinyl siloxane material (Kerr Australia, Lane Cove West, NSW), and firm finger pressure. The material had a different colour from the teeth and restoration to facilitate the measurement. Before setting, the excess material was removed by a dental explorer. The marginal gap was measured using a Nikon Travelling Microscope (Nikon Instruments Inc., Melville, NY, USA) calibrated to an accuracy of 0.001 mm. The tooth with the restoration was seated in place on the microscope platform using wax, and the measured surface was oriented parallel to the microscope lens. The vertical distance between the restoration margin and the cavosurface tooth margin representing the marginal gap was measured in µm along the whole margin at 1 mm increments by two designated evaluators. The two evaluators were trained on using the microscope, and an intraclass correlation test found a similarity of 91.8% between the 2 evaluators. In addition, the marginal gap measurements were categorized according to the different surfaces of the preparations. For the crown *(Figure 2A)*, the surfaces were proximal (P) and buccolingual (BL). For the inlay *(Figure 2B)*, the different surfaces were occlusal (O), proximal (P) representing the margin at the floor of the box, and axial (A) representing the buccolingual axial surfaces of the box. For the onlay *(Figure 2C)*, the different surfaces were buccolingual (BL), proximal (P) and axial (A).

The median and interquartile range (IQR) of the marginal gap were calculated for each restoration type and for each surface of every scanning system. The differences in the marginal gaps were analysed with the SPSS software package (SPSS for Windows, v23; SPSS Inc, Chicago, Illinois). The Shapiro Wilk normality test was conducted to evaluate the normality of the data. A series of Kruskal–Wallis tests were performed, followed by the Mann–Whitney U tests for intragroup evaluation. The levels of comparisons were: (1) comparison of restoration types within each scanner group, (2) comparison of the same restoration type between the different scanner groups, (3) comparison of the different surfaces of the same restoration within each scanner group, and (4) comparison of the similar surfaces of each restoration between the different scanner groups. The level of significance for all the statistical tests was set at 0.05. In addition, the data were presented in Box-and-Whisker plots.

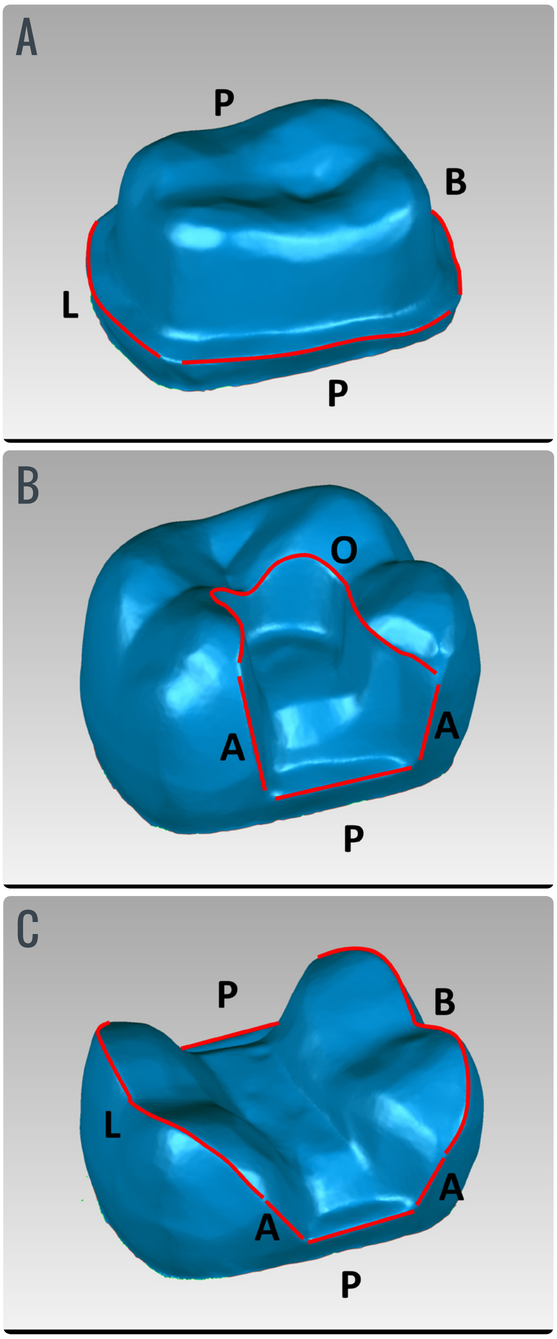

Figure 2: The segmented surfaces of the crown preparation (A), inlay preparation (B) and onlay preparation (C). A = axial surface, B = buccal surface, L = lingual surface, O = occlusal surface, and P = proximal surface.

RESULTS

The results of the marginal gaps of every restoration type were summarized in Table 1. For the BC, the crowns had the least marginal gap (median 113.9 µm; IQR 30.6 µm) followed by inlays (median 120.9 µm; IQR 28.3 µm) and onlays (median 132.5 µm; IQR 66.8 µm) respectively *(Figure 3)*. However, the difference among them was not significant (p = 0.20). On the contrary, for the OC, there was a significant difference among the different restorations (p = 0.003), where crowns had the least marginal gap (median 72.2 µm; median 10.7 µm), followed by inlays (median 74.9 µm; median 4.3 µm) and onlays (median 96.4 µm; median 25.6 µm) respectively. There was no significant difference between the crowns and the inlays (p = 0.46). Significant differences were observed between the crowns and the onlays (p = 0.01), and between the inlays and the onlays (p = 0.02).

The scanning system seemed to have an impact on the magnitude of the marginal gap of the restorations, where the OC provided a superior outcome to the BC for every restoration type. This was significant for the crowns (p < 0.001) and the inlays (p < 0.001). However, no significant difference between the BC and OC was observed for the onlays (p = 0.09).

The marginal gaps of the different surfaces were summarized in Table 2 and represented in Figure 4. For the BC, significant differences were observed for the different surfaces of the inlays (p = 0.04), but not for the crowns (p = 0.65), or the onlays (p = 0.29). For the inlays *(Figure 4B)*, the P surfaces

Table 1. The marginal gap of the crowns, inlays and onlays of the BC and the OC scanners

	BC			OC		
Restoration type	Crown	Inlay	Onlay	Crown	Inlay	Onlay
Median (µm)	113.9	120.9	132.5	72.2	74.9	96.4
Interquartile range (µm)	30.6	28.3	66.8	10.7	4.3	25.6
Mean (µm)	108.8	116.2	133.3	72.4	75.1	104.1
SD (µm)	21.9	29.0	38.5	8.6	7.1	34.3
Maximum (µm)	144.7	161.1	190.8	86.2	89.5	187.4
Minimum (µm)	74.2	56.8	85.2	58.0	61.4	74.7

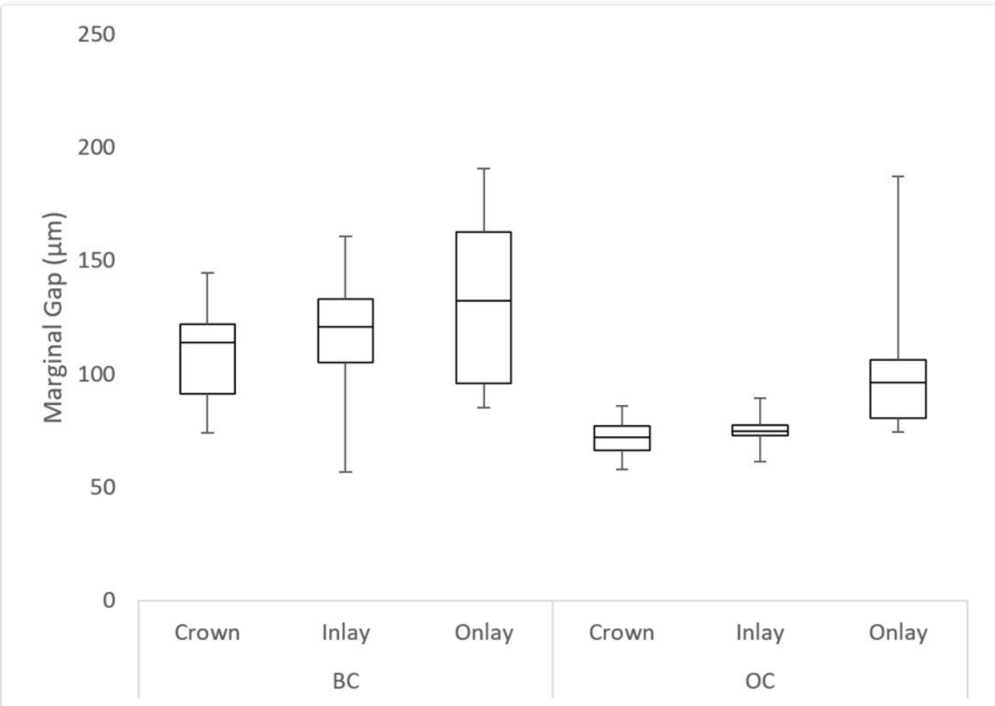

Figure 3: Box-and-Whisker plot summarizing the marginal gap of the different restorations for each scanner.

Table 2. The marginal gap of the different surfaces of the crowns, inlays and onlays of each scanner

	Crown			
	BC		OC	
Surface	BL	P	BL	P
Median (µm)	107.5	103.8	67.6	76.3
Interquartile range (µm)	39.2	27.0	15.9	15.9
Mean (µm)	111.7	106.4	67.8	76.2
SD (µm)	28.5	22.3	8.8	11.0
Maximum (µm)	159.0	146.6	78.9	92.9
Minimum (µm)	64.5	77.7	56.1	59.6

	Inlay					
	BC			OC		
Surface	O	P	A	O	P	A
Median (µm)	85.7	150.3	123.0	62.0	75.8	95.4
Interquartile range (µm)	61.2	87.0	44.1	5.4	34.2	3.9
Mean (µm)	100.8	152.6	120.4	60.6	80.7	97.1
SD (µm)	36.6	51.6	38.2	6.1	25.7	10.5
Maximum (µm)	147.5	211.2	188.1	69.0	118.7	116.5
Minimum (µm)	53.0	65.5	58.7	46.6	45.3	78.0

	Onlay					
	BC			OC		
Surface	BL	P	A	BL	P	A
Median (µm)	132.4	161.2	113.2	110.7	101.5	80.9
Interquartile range (µm)	61.2	112.0	28.9	37.7	19.5	18.7
Mean (µm)	137.1	160.8	113.6	122.6	113.5	83.9
SD (µm)	42.2	65.9	32.9	43.1	46.7	21.8
Maximum (µm)	208.4	242.7	169.7	228.1	214.4	139.4
Minimum (µm)	86.0	72.5	63.1	85.4	60.2	64.9

were less accurate than the A and the O surfaces. Significant difference existed only between the P and the O surfaces ($p = 0.01$). For the OC, a significant difference was observed between the different surfaces of the inlays ($p = 0.001$), where the A surfaces were most inferior, and significant difference was observed between the A and the O surfaces (0.000). No significant differences were detected for the different surfaces of the crowns ($p = 0.06$) and the onlays ($p = 0.08$).

Comparing the BC with the OC at the different surfaces indicated an overall inferior outcome for the BC compared with the OC. This was significant for the crowns at the P ($p = 0.003$) and the BL ($p = 0.001$) surfaces, and for the inlays at the P ($p = 0.01$) and the O ($p = 0.01$) surfaces. The BC and the OC did not differ significantly at the different surfaces of the onlays.

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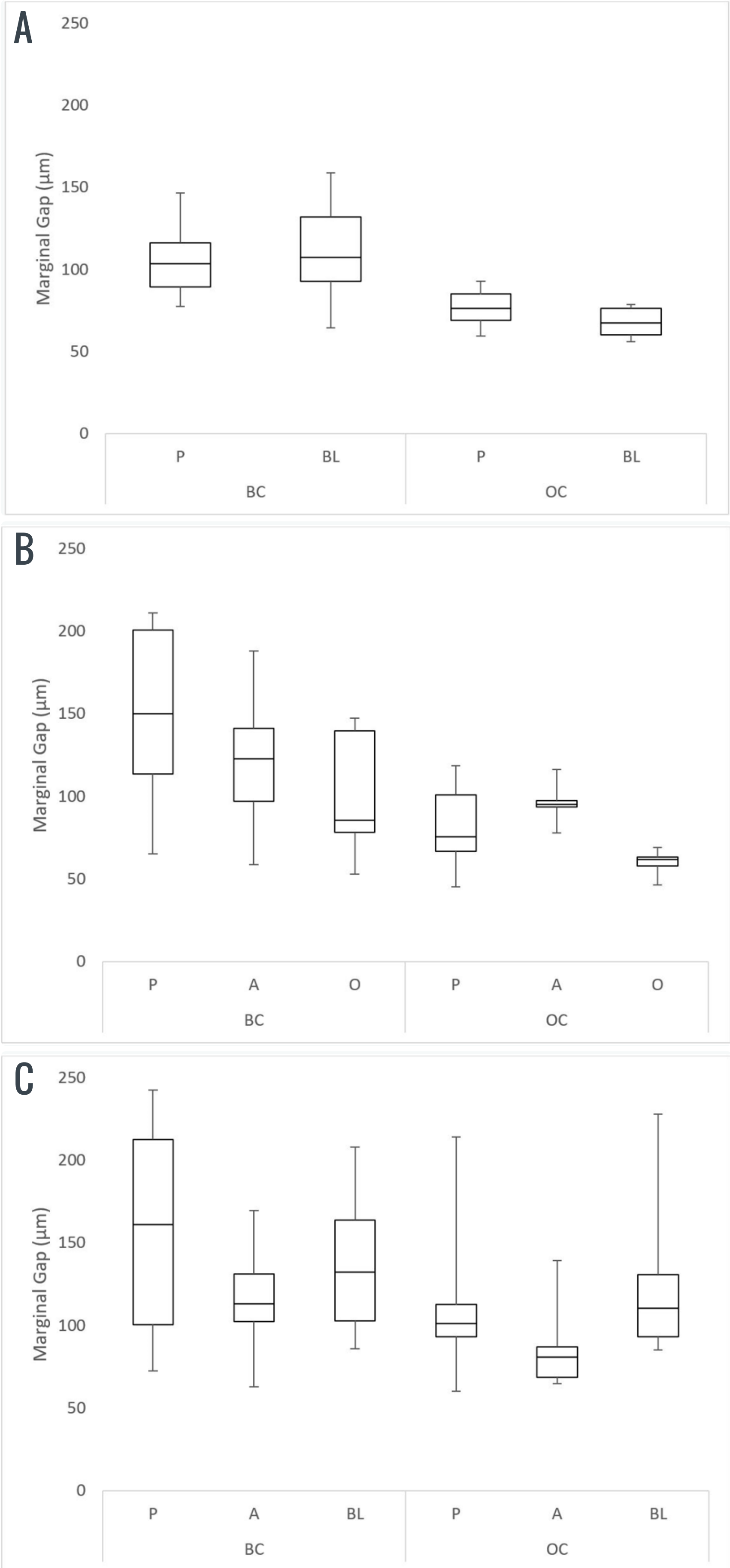

Figure 4: Box-and-Whisker plots summarizing the marginal gap of crowns (A), inlays (B) and onlays (C)

DISCUSSION

This study revealed that the restoration type and the intraoral scanner can have an impact on the marginal fit accuracy of the produced restoration. As significant difference was observed only for the OC group, the null hypothesis that there is no effect of the chairside CAD/CAM restoration type on the marginal fit accuracy is rejected for the OC, but accepted for the BC. Nevertheless, the OC was clearly more superior than the BC for all the levels of comparison. Thus, the null hypothesis that there is no effect of the different scanners by the same CAD/CAM manufacturer was rejected. Further, the location of the scanned surfaces seemed to have an effect on marginal gap only for the inlays, where the proximal surfaces (box floor) of the BC inlays and axial surfaces of the OC inlays were more inaccurate than the other surfaces. In the present study, OC and BC were included as they are commonly available systems in dental clinics from the same manufacturer. Further, these 2 systems use similar software and milling machine. Therefore, the differences in the fit of the restorations can be attributed purely to the scanning unit and the restoration type. Nevertheless, as per several published reports, the mean marginal gap values for all of the restorations were close to the 100-200 µm level for a clinically acceptable marginal gap for long term prognosis.[5-12,17,18]

Overall, there is a trend for the crowns of the present study to have better marginal fit than inlays and onlays. This difference can be due to preparation geometry that may influence scanning, virtual margin determination, milling and restoration fitting. For the crown preparation, the margins are even, supragingival and accessible to scanning, even at the proximal surfaces.[20] Further, all the line angles are rounded which makes it easier to scan the preparation and mill the restoration.[20] This is clearly observed by the similarity in the marginal gap at the proximal and buccolingual locations. On the contrary, the morphology of the inlay and onlay preparations are more complex than crown preparation which poses extra challenges on the scanning.[2,21] Specifically, 2 features of the preparation may influence the accuracy, the location of the scanned surface, and the scanned surface morphology. For example, proximal boxes of onlays and inlays seemed to be more difficult to scan due to the presence of buccal and palatal walls, which with the presence of adjacent teeth may have interfered with scanning light projection.[21] The BC scanning is further affected by the entrapment of antireflective powder at the proximal boxes leading to more inferior scanning outcome.[6,20] Further, the occlusal aspect of the margins of the inlays and onlays are more corrugated than the crown margins which may further interfere with scanning accuracy, margin determination and accurate milling.[2,5,19,22-24] Earlier studies that measured trueness and precision found steep regions, proximal surfaces and corrugated outlines interfered with scanning, and were associated with greater inaccuracies.[21,25,26] This may also explain the inferior outcome of the onlay restorations since the onlay preparation had more surfaces with more complex geometry. A systematic review of 14 studies identified the CAD/CAM milled onlays exhibited marginal gaps ranging from 68 µm to 201 µm compared to a range of 36 µm to 121 µm for the inlays.[1]

Another explanation for the different margin accuracies on different restoration types is the nature of seating of the restoration, where the restorations that have a more defined path of insertion and seating have better fit.[20,27] As the crown is seated on the prepared tooth, the margins of the preparation serve as vertical stops. Since a virtual die space was added, the marginal gap will be reduced as soon as the crown margin contacts the tooth. Moreover, the crowns have more features to provide stability and resistance to horizontal movement. Similarly, the inlay preparation applied in this study allowed for definite seating and with vertical features to provide stability. On the contrary, the onlay preparations have flat cuspal morphology, with only the shallow boxes and isthmus providing minimal lateral stability. Minor seating errors of the onlay will translate into marginal discrepancies. Similar findings were observed by Lima *et al*. that compared onlay preparations with flat cuspal reduction against onlay preparations with axial reduction in a form of shoulder margin. They reported significantly better margin accuracy when axial reduction was incorporated in the preparation.[20] Similarly, Yang *et al*. found that onlays with heavy chamfer had a significantly smaller overall marginal gap than onlays with flat cuspal reduction.[27] The 2 studies attributed their observation to the ease of scanning of the chamfer preparation and the more defined seating and stability of the restoration that prevents inaccurate placement of the onlays.[20,27]

According to the present study, the 2 scanners were associated with errors that most likely are inevitable. This can be derived from the chairside CAD/CAM workflow consisting of scanning with an intraoral scanner, manual virtual tracing of preparation margin, CAD modelling with manufacturer software, and CAM production with a milling unit.[28-30] However, there is a clear tendency of a more superior outcome for the OC than the BC which can be attributed to the advancement in the technology and scanning approach, which will eventually improves the precision, trueness and image resolution. The BC works by snap imaging of powdered surface with antireflective powder. While necessary to reduce the reflectiveness of the surface, the powder may add a layer on the scanned surface that can influence the accuracy of the scanning.[6] This was clearly shown with the inferior outcome of the boxes of the inlays and onlays that most likely trapped the powder in the confined regions. Further the multiple images will require automated superimposition that can potentially affect the accuracy. On the contrary, OC is based on continuous imaging that ensures more frequent and automated overlap between the multiple images. As it is a quicker mechanism and does not require powder, the chance of error is reduced. Also, the OC scanner allows for a real time visualization of the scanning process that provides immediate feedback to the operators, possibly ensuring a better scanning outcome. However, despite the statistical differences, the 2 scanners evaluated in this study can produce restorations of acceptable fit accuracy.[3,4,31,32] While marginal gaps differed between the different restoration types and scanners, the clinical significance of this difference is yet to be determined. This is important in the light that the longevity of all these restorations was established by clinical studies.[33-35] Therefore, the clinical implications of the measured misfit of this study is yet to be established.

The results of this study should be cautiously interpreted. The study had several limitations related to its methodology such as fitting the restorations on the prepared teeth without the adjacent teeth and proximal contacts. The laboratory setup did not simulate clinical parameters such as intraoral access, natural dental tissue, humidity, saliva and patient movement that will influence the accuracy of scanning. The present study seemed to show a marginal gap of larger magnitude than other recent studies, which can be related to seating the restorations with impression material.[18] In the present study, the use of impression material was necessary for attaching the restoration and providing colour contrast. The studies on the fit of CAD/CAM restorations had great heterogeneity with multiple confounding variables, which made the comparison difficult and not feasible.[2,4,21] This involves prepared margin design, margin location, presence or absence of adjacent teeth, and whether the restorations were cemented on the teeth.[2,18,21] Furthermore, marginal gap measurements were conducted only in the vertical dimension, and horizontal marginal discrepancies were not considered.

CONCLUSIONS

Regardless of the chairside CAD/CAM systems, different restoration types exhibited different marginal gap, where the crowns tended to have the least marginal gap, while the onlays had the greatest marginal gap. The newer system (OC) was more accurate than the older system (BC). Upon evaluation of the different surfaces, inlays tend to have more variations among the different surfaces. The crowns and the onlays did not show a clear pattern of variations among the different surfaces.

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