Original Article

Comparative Evaluation of the Marginal Fit of Inlays Fabricated by Conventional and Digital Impression Techniques: A Stereomicroscopic Study

Abstract

Context: Marginal fit being the prime concern of indirect restorations. Inlays can be either fabricated by conventional technique or computer-aided design and computer-aided manufacturing (CAD/CAM) techniques. CAD/CAM is the most evolving digital technique with faster, quicker, and precise results. **Aims:** The aim of this study is to evaluate and compare the marginal fit of MOD inlays fabricated with two different CAD/CAM methods and conventional fabrication methods. **Settings and Design:** Mesio-occlusal-distal preparation was done on a maxillary premolar typhodont tooth and divided into the following groups. Group A: 30 inlays were fabricated through the conventional impression technique. Group B: Preparation was scanning using an intraoral scanner followed by subtractive milling (Group B1) and subtractive milling of wax patterns (Group B2). Similarly, subgrouping was carried out for Group C except that an extraoral scanner was used. Occlusal and the cervical marginal fit were assessed using the replica technique and stereomicroscope. One-way ANOVA followed by Tukey honestly significant difference *post hoc* test for determining differences at a 95% level of confidence ($P = 0.05$). **Results:** Group A had the highest marginal discrepancy in comparison to Group B and Group C at occlusal and cervical edges, whereas subtractive milling showed comparatively better results than subtractive milling of wax patterns at cervical edges and similar results at occlusal edges. **Conclusions:** Ceramic inlays fabricated by subtractive milling yielded better results.

Keywords: *Computer-aided design and computer-aided manufacturing, conventional impression, digital impression, inlays, marginal fit, subtractive milling, wax patterns*

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Introduction

The clinical success of indirect restoration depends on many factors, and marginal adaptation is one such criterion. Proper marginal fit is required to prevent microleakage for oral pathogens, and subsequent secondary caries and pulpal involvement.[1] The marginal fit is basically defined as a straight line contact or a gap-less transition between the preparation and the margin of the restoration. Several studies have shown different values for clinically acceptable marginal fit; however, there is no common consensus regarding the same. Christensen observed that margins extending more than 39 µm are clinically undesirable.[2] McLean and von Fraunhofer considered that <120 µm gap is clinically acceptable.[3] Holmes *et al.* showed that ideally a gap between the margins in the range of 50 and 100 µm is considered to be technically practicable.[4] For this study, 120 µm was considered the maximum clinically acceptable gap size. For a better marginal adaptation, an accurate impression is needed. Better impressions always work as an association between the dentists and the technicians for an accurate replication in the clinical scenarios. To achieve accurate casts and subsequent fittings of restorations a precise impression is needed.[5] No special types of equipment are required for conventional impression technique, and just by following precise working steps, an accurate impression can be achieved. The accuracy of impression is impacted by many factors such as excessive salivary flow, undercuts, storage for a longer period, moistness, material irregularities. Such undesirable factors are responsible for misfit and imprecisions of restorations.[6] Along with a good impression, the assembly of the wax pattern is an important step in

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the fabrication of indirect restorations. Skills of dental technicians determine the time consumption, keeping in mind also the limitations while working with wax Handling of wax leads to shrinkage of around 0.4%.[7] Apart from conventional impressions and fabrication of wax patterns recent advancements have been introduced through the practice of advanced technology such as subtractive milling with computer-aided design and computer-aided manufacturing (CAD/CAM) system for taking good impressions, and fabrication of wax patterns.[8]

CAD/CAM system is of two types: the direct/chairside model and indirect/laboratory side model. The direct method involves the use of the intraoral scanner for taking a direct impression of preparation, and the restoration is further designed and milled in the dentist's office. The indirect method involves obtaining a conventional impression with an elastomeric material, which is further scanned within the laboratory using an extraoral scanner.[1] The main aim is to attain impressions digitally that makes the fabrication process easier with much improved patient comfort level.[9] The omission of both midway assembly steps such as tray selection, tray try out, impression disinfection, transportation, plaster pouring, trimming or articulation, and the probable cause of the error is of remarkable clinical significance. It helps in real-time imaging and chair-side surveying of the tooth preparation as well as careful scanning of selective areas, digital filing, and rapid communication with the laboratory.[10,11] Literature exists where conventional and digital techniques have been compared and documented. Several studies showed that digital impression method shows similar or better results than the conventional two-step method.[1,7,12,13] While some studies showed that the conventional method showed a better fit than the subtractive milling/CAD/CAM technique.[14-19]

Few studies exist where conventional wax patterns are compared to subtractive milling of wax patterns. However till date, no study has been documented where direct/subtractive milling is compared to subtractive CAD/CAM wax patterns using the same scanner. The purpose of this study is to evaluate and compare the marginal fit of MOD inlays fabricated with two different CAD/CAM methods (subtractive milling and subtractive milling of wax patterns) and a conventional waxing/fabrication method. The null hypothesis was that there would be no difference in the marginal fit of inlay between conventional and two different CAD/CAM methods.

Materials and Methods

A left maxillary second premolar typodont tooth (API, AshooSons, Delhi, India) was selected for this study. This study was conducted in the department with technical support collaboration Dentsway Lab, Faridabad. Class II mesio-occluso-distal inlay preparation was done on a typodont (API, AshooSons, India) maxillary left second premolar using carbide burs (no. 271 and no. 169 L) (SS White®, Lakewood, New Jersey) and a high-speed handpiece (Pana-air, NSK LTD, Japan). The design included a 3 mm deep occlusal box, 3 mm wide buccolingual width.[1] All the internal angles were rounded. Free-hand preparation was done, and later dimensions were verified with the help of digital vernier caliper (Aerospace) and William's periodontal probe (API, AshooSons, Delhi, India).

Ninety inlays fabricated according to experimental design, were equally distributed in three groups of 30 inlays each. Of three, two groups (B and C) were further divided into two subgroups [Figure 1].

Irreversible hydrocolloid impression of the prepared cavity was taken to produce cast for the fabrication of thirty partial custom trays (®DPI-RR Cold Cure, India) with occlusal rests. Thirty elastomeric impressions were taken with the help of custom trays using light-and heavy-body polyvinyl siloxane (AFFINIS® Perfect Impressions, Coltene). Type IV stone was used to pour the cast (Kalabhai, Kalrock, India) following the manufacturer's instructions and under standardized conditions. Thirty standardized wax patterns were prepared using inlay wax sticks (MDM® Blue Inlay Wax, India) to replicate the anatomy of maxillary 2nd premolar. The wax patterns were further processed. The lost wax technique was applied to invest the wax patterns with phosphate bonded investment material and pressed according to the company's instructions (Group A).

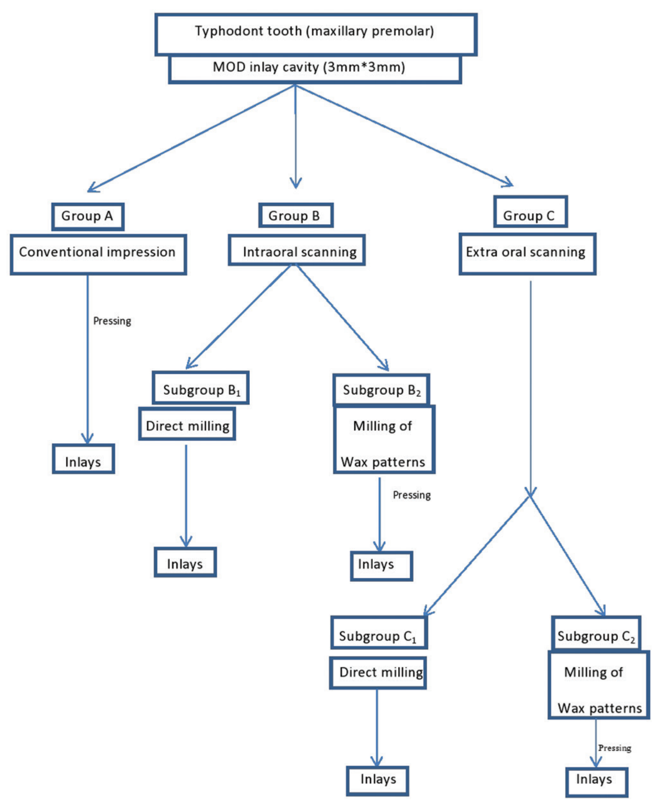

Figure 1: Experimental design

A single digital impression was taken of the prepared tooth with an intraoral scanner (Trios; 3shape) [Figure 2], and the stereolithography file was sent to the laboratory. The designing part was done in Exocad software. The marginal discrepancy was set to 0 µm and margin thickness at 0.2 µm. The replicated die spacer was set to 30 µm, starting away from the margin. Applying this design, 15 ceramic inlays were produced using zirconia-based ceramic blanks (Cercon HT, DeguDent, Dentsply Sirona) in a milling machine (YENADENT D15, Vierzon, France) (Group B1).

Similarly, 15 wax patterns were produced using the wax blanks (YAMAHACHI, Aichi Pref. Japan) in a milling machine (YENADENT D15, Vierzon, France) and which is further invested and processed to obtain 15 ceramic inlays (Group B2). A die was prepared by pouring a conventional polyvinyl siloxane impression of the prepared cavity using Type IV gypsum stone. The die was scanned with extra-oral/laboratory scanner (dental wings 7SERIES, Montreal, Canada) [Figure 3]. The inlay was designed using the DWOS (Dental Wings Open System). Further nesting was done in WorkNC software, and the instruction was sent to the milling machine to produce 15 ceramic inlays using zirconia-based ceramic blanks (Cercon HT, Degudent, Dentsply Sirona) (Group C1). The same design was used to produce 15 wax patterns in a milling machine (YENADENT D15, Vierzon, France) using wax blanks (YAMAHACHI, Japan) and which is further invested and pressed according to the manufacturer's approvals to 15 ceramic inlays (Group C2).

All the inlays in the three groups were transported to master cavity preparation, and slight adjustments were made with water-cooled diamond rotary instruments. The whole procedure was done by the same operator. The cavity walls were coated with a thin layer of light-body silicone material to produce replication of the space between the inner surface of the inlay and the cavity surfaces, following which the inlay was placed in the prepared cavity. Constant pressure of 750 g was applied to inlay until the materials got fully polymerized.[1] The excess was removed, and the inlay was removed from the prepared cavity leaving behind a thin film of light-body impression material. Heavy-body impression material was applied on top of the cavity to stabilize the light-body impression material and to avoid its distortion. In the presence of distortion or any other defects of silicone film, the replicas were rejected, and the method was repeated.

Two replicas of each sample were fabricated. The replicas were cut in two different directions. One replica was cut in mesiodistal direction, and the other was cut in the buccolingual direction to assess the occlusal and cervical edges [Figures 4 and 5].

Seven locations were assessed for the marginal fit. Three locations (O1, O2, O3) in occlusal edge and four locations in cervical edges (mesial side [M1, M2], distal side [D1, D2]) were assessed [Figure 6]. Measurement of the marginal fit using the parameter of the thickness of the light-body silicone material was done by stereomicroscope. The marginal fit was assessed using a stereomicroscope at x40 magnification (Magnus, Magnus Opto Systems, India Pvt. Ltd.). All the measurements were then sent to statistical analysis.

Statistical analysis was performed using one-way ANOVA followed by Tukey honestly significant difference (HSD)

Figure 2: Intraoral scanner

Figure 3: Extraoral scanner

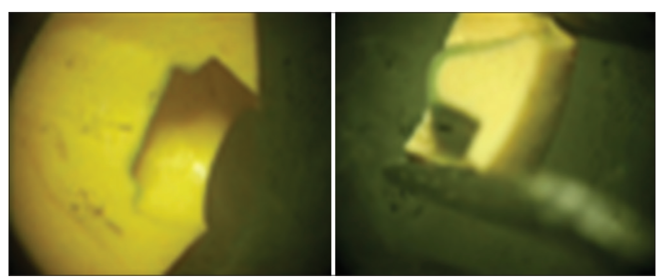

Figure 4: Replicas cut in mesiodistal and buccolingual direction to assess the marginal fit under stereomicroscope

post hoc test for multiple comparisons. Data were presented as mean + standard deviation. Paired *t*-test was used to see the relative change with respect to time and unpaired *t*-test was applied to compare mean values between the two groups. $P < 0.05$ considered as statistically significant at 95% confidence level. The statistical software SPSS 18.0 was used in the analysis.

Results

One-way ANOVA followed by Tukey HSD *post hoc* test was used to the relative change with respect to time, and unpaired *t*-test was applied to compare the mean values between the two groups.

On the comparison between three groups (Group A, B, and C), there was a significant difference at various locations [cervical edges (M1, M2, D1, D2) and occlusal edges (O1, O2, O3)]. Whereas Group A showed the highest amount of marginal discrepancy as compared to B and C at all the measured locations.($P < 0.05$) Group B shows the least amount of marginal discrepancy at all the measured location with the best results.($P > 0.05$) However, there was no statically significant difference between Group B and Group C at measured locations [Table 1].

On the comparison between subtractive milled (Group B1) and subtractive milling of wax patterns (Group B2), there were significant differences at the cervical edges (M1, M2, D1, D2) ($P < 0.05$). Nonsignificant difference at occlusal edges (O1, O2, O3) in between these two groups ($P > 0.05$) [Table 2].

On the comparison between subtractive milled inlays (Group C1) or subtractive milling of wax patterns (Group C2), there was no significant difference at the measured locations (cervical edges [M1, M2, D1, D2] and occlusal edges [O1, O2, O3]) ($P > 0.05$) [Table 3]. Overall comparison between the 3 groups with their mean values and standard deviations is summarized in Table 4.

Discussion

The purpose of this study to evaluate and compare the marginal fit of MOD inlays fabricated with two different CAD/CAM methods (subtractive milling and subtractive milling of wax patterns) and conventional waxing/fabrication method. The results support the rejection of the null hypothesis stating that no differences would be found in the marginal fit of inlay between conventional and two different CAD/CAM methods. Marginal gap size being the prime concern of this study.

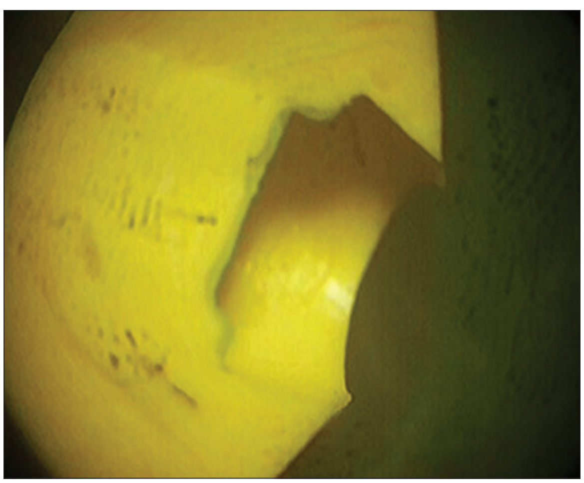

Figure 5: Replica viewed under stereomicrope (indicating light body [green] and heavy body [orange])

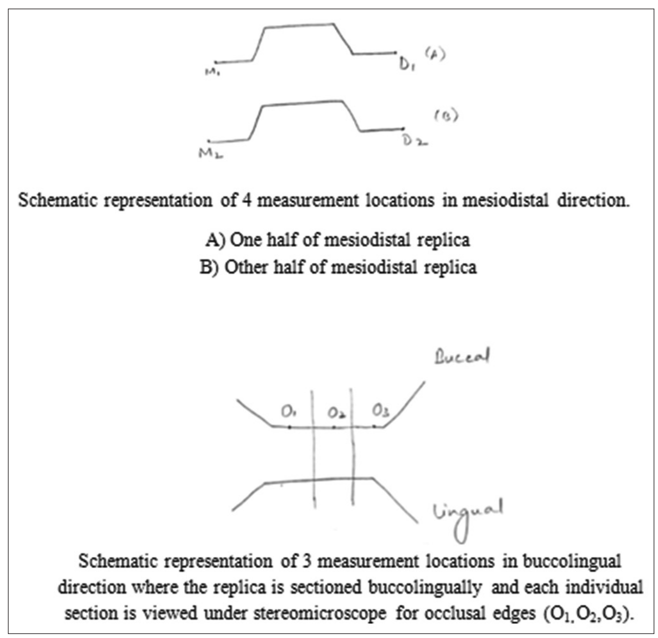

Figure 6: Schematic diagram of measurement locations in mesial side and buccal side direction

Table 1: Tukey honestly significant difference *post hoc* tests for Multiple comparisons among the three groups

Groups	Cervical edge M1	Cervical edge M2	Cervical edge D1	Cervical edge D2	Occlusal edge O1	Occlusal edge O2	Occlusal edge O3
A-B	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
C	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
B-A	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
C	0.252	0.181	0.251	0.177	0.554	0.429	0.883
C-A	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
B	0.252	0.181	0.251	0.177	0.554	0.429	0.883

Table 2: Mean values along with standard deviations among the subgroups (B_1 and B_2)

	Subgroup	*n*	Mean	SD	*t*	*P*
Cervical	B1	15	36.28	1.55	7.434	<0.001
edge M1	B2	15	40.73	1.72		
Cervical	B1	15	36.16	1.66	6.55	<0.001
edge M2	B2	15	40.49	1.95		
Cervical	B1	15	35	1.54	7.906	<0.001
edge D1	B2	15	40.79	1.84		
Cervical	B1	15	35.53	1.90	7.602	<0.001
edge D2	B2	15	40.67	1.80		
Occlusal	B1	15	21.57	1.26	0.357	0.724
edge O1	B2	15	21.71	0.85		
Occlusal	B1	15	20.16	1.55	1.741	0.093
edge O2	B2	15	21.05	1.25		
Occlusal	B1	15	21.52	1.30	0.362	0.72
edge O3	B2	15	21.67	0.99		

SD: Standard deviation

Table 3: Mean values along with standard deviations among the subgroups (C_1 and C_2)

	Subgroups	*n* Mean	SD	*t*	*P*
Cervical	C1-15	40.28	1.39	2.213	0.035
Edge M1	C2-15	41.63	1.90		
Cervical	C1-15	40.43	1.27	1.782	0.086
edge M2	C2-15	41.47	1.89		
Cervical	C1-15	40.33	0.99	2.19	0.037
edge D1	C2-15	41.39	1.61		
Cervical	C1-15	40.10	1.16	2.676	0.012
edge D2	C2-15	41.51	1.69		
Occlusal	C1-15	21.27	0.92	0.56	0.58
edge O1	C2-15	21.47	1.04		
Occlusal	C1-15	21.13	1.25	0.477	0.637
edge O2	C2-15	20.91	1.28		
Occlusal	C1-15	21.41	0.90	0.353	0.727
edge O3	C2-15	21.53	0.86		

According to Hoop and Land, the inlay preparation for CAD/CAM should present 1.5–2 mm of pulpal floor depth, and the box walls should diverge in an occlusal direction, which makes the optical capture much easier and reduces the risk of excessive binding during seating for the initial evaluation.[20] In this experimental design, the preparation was a little deeper (3 mm) to stimulate the worst-case scenario. The experimental design was based according to Rippe *et al*. where the preparation depth was 3 mm deep cavity.[1]

In the first group (conventional technique), to avoid continuous damage to the die stone, it was imperative to produce 30 wax patterns on 30 casts. It was done by the same operator. In the second group, where an intraoral scanner was used having subgroups (B1 and B2), the prepared tooth was captured once with the intraoral scanner.[21] In the third group, where extraoral scanner was used, an individual stone die was fabricated from prepared typodont tooth. A single digital scanning was done with a laboratory scanner to eradicate any probable errors that might be related to the conventional impression workflow and inconsistencies related to scanning procedure.

Many variables such as tooth preparation design, location and number of measuring points, measuring techniques, types of resin cements and restoration production method influences the marginal gap size. All the factors should be taken into account for such studies.

The present study revealed that inlays fabricated by conventional technique showed a significant difference in marginal fit in all the measured locations (cervical and occlusal edges) than the other two digital impression techniques ($P < 0.05$) [Table 1]. Similar to our study, various studies have documented the CAD/CAM generated inlays showed comparatively better results than conventional techniques in terms of marginal fit.[7,21,22] Homsy *et al*. concluded that lithium disilicate glass-ceramic inlays fabricated from digital impressions and subtractive milling of wax patterns results in better marginal and internal fit accuracy than the conventional impressions.[21] Shamseddin *et al*. have also concluded that subtractive CAD/CAM waxing technique resulted in better marginal fit and internal fit than conventional waxing technique, both being within the clinically acceptable range.[7] Syrek *et al*. showed that crowns fabricated with Lava COS had a statistically significant smaller gap than conventional ones.[22] The pattern of wax distortion is different in milled and manual wax that could lead to a discrepancy. Manually fabricated wax shows contraction and expansion after unequal heating and cooling, while the wax used for CAD/CAM is more of a solid synthetic wax made from polymerization reaction and is less vulnerable to temperature settings.[23] More the number of interfaces in the workflow results in more discrepancies between the groups. As discussed earlier, an accurate impression is needed for accurate casts and subsequent fittings.[6] However, the results of the marginal fit of both the conventional and digital impression groups were in the clinically tolerable range.

On the other hand, in contradiction to the results interpreted, several studies reported that the pressed technique had a significantly lesser marginal gap size than those of CAD/CAM technique. The probable reason for the discrepancy could be the additional steps in the fabrication procedure that may lead to inaccuracies, namely scanning, software design, milling, and material processing.[24]

In the present study, while comparing the marginal discrepancy between intragroup (subgroup B1 and B2) and subgroup (C1 and C2) at different locations. Till date, no study has been documented to our knowledge in terms of comparison between CAD/CAM generated inlays (subtractive milling and subtractive milling of wax patterns and further investing it). The results showed

Table 4: Mean values of all groups along with their standard deviations and ranges

	n	Mean	SD	Minimum	Maximum	*F*	*P*
Cervical edge M1							
A	30	92.61	9.75	78.6	106.8	793.04	<0.001
B	30	38.50	2.78	33.6	43.7		
C	30	40.95	1.77	38.4	44.2		
Total	90	57.35	25.77	33.6	106.8		
Cervical edge M2							
A	30	92.34	9.30	77.7	105.7	857.655	<0.001
B	30	38.33	2.83	33.5	44.3		
C	30	40.95	1.67	38.2	44.3		
Total	90	57.20	25.63	33.5	105.7		
Cervical edge D1							
A	30	92.23	9.99	78.2	106.2	750.823	<0.001
B	30	38.35	2.99	33.7	44.5		
C	30	40.86	1.42	38.9	43.7		
Total	90	57.15	25.68	33.7	106.2		
Cervical edge D2							
A	30	92.56	9.45	76.7	106.3	831.689	<0.001
B	30	38.10	3.18	31.1	43.5		
C	30	40.81	1.59	38.5	44.1		
Total	90	57.16	25.85	31.1	106.3		
Occlusal edge O1							
A	30	28.63	0.91	26.8	30.6	528.99	<0.001
B	30	21.64	1.06	18.9	22.8		
C	30	21.37	0.97	19.7	22.8		
Total	90	23.88	3.52	18.9	30.6		
Occlusal edge O2							
A	30	28.39	1.17	26.5	30.7	343.589	<0.001
B	30	20.61	1.45	17.3	22.5		
C	30	21.02	1.25	17.7	22.8		
Total	90	23.34	3.82	17.3	30.7		
Occlusal edge O3							
A	30	28.69	1.06	27.1	31.6	482.361	<0.001
B	30	21.60	1.14	17.6	22.8		
C	30	21.47	0.87	19.3	22.8		
Total	90	23.92	3.54	17.6	31.6		

SD: Standard deviation

that there was significant differences in marginal fit at the cervical edges (M1, M2, M3, M4) ($P < 0.05$) and nonsignificant difference at occlusal level (O1, O2, O3) in between B1 and B2 groups ($P > 0.05$). In spite of using the same intraoral scanner and same design still, the difference could be because of the properties of wax blocks used for milling. The wax pattern distortions cannot be prevented due to the development of internal stain in the wax during preparation. The distortion is both time, and temperature-dependent and ideally, patterns should be invested immediately after their fabrication.[25,26] Whereas the subgroups (C1 and C2) showed similar results of marginal discrepancy in terms of cervical and occlusal edges scanned by the same laboratory scanner.

The intragroup comparison showed the comparison between Group B1 (direct fabrication of inlays) and Group B2 (Milling of wax patterns) using an intraoral scanner analyzed by Student's *t*-test where $P < 0.05$. The marginal discrepancy values of Group B1 were significantly lower than Group B2 at cervical edges (M1, M2, D1, D2) ($P < 0.05$), whereas at occlusal edges (O1, O2, O3), there was no significant difference between Group B1 and Group B2 ($P > 0.05$). To the best of our knowledge, no study has been documented in terms of comparison between CAD/CAM generated inlays (direct fabrication of inlays and CAD/CAM generated wax patterns). Despite using the same intraoral scanner and same design, the difference could be because of the properties of wax blocks used for milling.

Another intragroup comparison showed the comparison between Group C1 (direct fabrication of inlays) and Group C2 (Milling of wax patterns) using extra-oral scanner analyzed using Student's *t*-test where $P < 0.05$. The marginal discrepancy values were nonsignificant at both cervical (M1, M2, D1, D2) and occlusal edges (O1, O2, O3) ($P < 0.05$).

Furthermore, the comparison between Group B1 (direct fabrication of inlays) using the intraoral scanner and Group C1 (direct fabrication of inlays) using extra-oral scanner showed that the marginal discrepancy of B1 subgroup (scanned by the intraoral scanner) had better results than C1 subgroup (scanned by laboratory scanner) with respect to cervical edges (M1, M2, D1, D2) ($P < 0.05$) but nonsignificant difference in terms of occlusal edges (O1, O2, O3) ($P > 0.05$). It is difficult to explain these discrepancies due to less documented data in the existing literature. However, the mean marginal discrepancy difference between groups B1 and C1 was less, which was considered insignificant at the clinical level. Homsy *et al*. also concluded similar results in between these digital impression techniques.[21]

The comparison between Group B2 (Milling of wax patterns) using the intraoral scanner and Group C2 (Milling of wax patterns) using an extraoral scanner. showed that in between Groups C1 and C2, there was nonsignificant difference in terms of cervical (M1, M2, D1, D2) and occlusal edges (O1, O2, O3) ($P > 0.05$) for assessing the marginal gap indicating that the impression technique does not effect the adaptability of the milling of wax patterns and further investing it. Similar results with respect to adaptation can be obtained with both the techniques, intraoral digital scanning followed by sending it to the laboratory, as well as taking conventional impressions that are then scanned to create wax patterns.[21] The other probable reason could be the properties of wax where in both cases, the distortion of wax could be of the same level resulting in similar values.

These results, in amalgamation with the findings of our study, suggest that digital workflow performs better than conventional workflow, both being in the clinically acceptable range.

A well-documented, nondestructive replica technique is used to assess the marginal gap.[27] It is a very reliable technique to evaluate the marginal discrepancy and yields results similar to conventional cementation.[28] However, this technique has inbuilt errors related to problems in pointing out the margins of inlay, distortion elastomeric film during removal, the existence of defects in the silicone films, and inaccuracies in the sectioning planes. The load applied for inlay seating into the prepared cavity needs to be carefully standardized and discard the replicas with defects. This replica technique couldn't conclude a clinical test value as, according to Groten *et al*. suggested 50 measurements are needed. For the present study, the area to be measured was restricted to the sectioned line.[29]

A common question that might arise is that despite the availability and access to CAD/CAM equipment, Why would the clinicians manually fabricate wax patterns for inlay restorations?. Several factors influence clinicians to use the pressed technique or by milling of wax patterns and further investing it. Cost factor being the major one, the laboratory costs involved in milling of wax patterns and further pressing it or simply the pressable ones are much affordable than the direct CAD/CAM restorations.

Although it may seem as an expensive option, the technique is slowly getting upgraded with regular dental practices and may prevent the failures in restorations to happen in the years to come.

Conclusions

On of basis of our study, the following conclusions were made that digital impression techniques performed better than conventional impression techniques. The subtractive milling performed comparatively better than subtractive milling of wax patterns but with negligible difference in terms of marginal fit of MOD inlays.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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