EGYPTIAN
DENTAL JOURNAL

Vol. 65, 3007:3018, July, 2019

I.S.S.N 0070-9484

Fixed Prosthodontics, Dental materials, Conservative Dentistry and Endodontics

www.eda-egypt.org • Codex : 212/1907

MARGINAL INTEGRITY OF GLASS CERAMIC LAMINATE VENEERS PRODUCED THROUGH DIFFERENT CAD/CAM MILLING PROTOCOLS: IN-VITRO STUDY

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ABSTRACT

Statement of the problem: The conservative nature of the labial ceramic veneers necessitates minimum amount of tooth reduction with thin peripheral margins. Since construction time of restorations is becoming a determinant factor together with accuracy, the effect of three different CAD/CAM milling protocols that depend on the time factor deserves to be assessed.

Purpose: The purpose of this investigation was to evaluate the effect of three different CAD/CAM milling protocols; namely normal, fast, and two-step milling on the peripheral marginal accuracy of glass-ceramic laminate veneers.

Materials and Methods: A maxillary central incisor acrylic tooth was chosen to serve as a die for veneer construction. Acrylic tooth preparation was done to receive incisal feather edge design for the ceramic veneer. A total of thirty laminate veneer restorations were constructed from IPS e.max CAD glass ceramic using the CAD/CAM technology with three different milling protocols. The veneers were divided into the following groups according to the selected milling protocol; ***Group 1:*** Ten veneers constructed using the normal milling protocol, ***Group 2***: Ten veneers constructed using the fast milling protocol, ***Group 3***: Ten veneers constructed using the two-step milling protocol. The milled veneers were subjected to crystallization process according to manufacturer's instructions then they were checked on their corresponding die for proper adaptation and seating. For proper assessment of the vertical marginal gap, the veneers were fixed on the master die using one drop of adhesive placed centrally to stabilize the veneers in their place during the measuring procedure. The vertical marginal gap distance of each ceramic was measured using a stereomicroscope at magnification X45. The measurements were done along the peripheral circumference for all the veneer margins (mesial, distal, cervical and incisal). Measurement at each point was repeated five times. A digital image analysis system was used for assessing and evaluating vertical marginal gap width. The mean vertical marginal gap distance was calculated and then tabulated for the statistical analysis of the data.

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Results: Effect of milling protocol: The two-step milling protocol showed the statistically significant lowest mean marginal gap distance (33.2 ± 6.3 μm) while both the normal and fast milling protocols showed the statistically significant highest mean marginal gap distances with no statistically significant difference between them. (40 ± 7.5 μm and 41.2 ± 4.9 μm respectively) ***Effect of surface:*** The cervical surface recorded the statistically significant lowest mean marginal gap distance (34 ± 6.5 μm) while the distal surface recorded the highest mean marginal gap distance (41.6 ± 8.6 μm) with non-statistically significant difference from incisal (37.2 ± 4.6 μm) and mesial surface (39.7 ± 6.4 μm).

Conclusions: Within the limitations of this in-vitro study, the following conclusions were drawn: 1) Marginal discrepancy of all groups fell within the clinically acceptable value, thus the three milling protocols can be safely used. 2)Veneers fabricated using the two-step milling protocol exhibited the least marginal discrepancy among other experimental groups, thus it can be used as the protocol of preference if restoration accuracy is of utmost importance. 3) Since there was no significant difference between normal and fast milling protocols regarding marginal discrepancy, therefore fast milling can be recommended for veneer fabrication if chairside time is of prime importance in some cases. 4) Cervical marginal discrepancy was found to have the least value compared to other surfaces

INTRODUCTION

Ceramic laminate veneers are becoming now very popular conservative solution restoring many cases including diastemas, chipped and discolored teeth. Since its evolution, many materials have been used for its fabrication starting with normal feldspathic ceramics [1]. However, with the introduction of lithium disilicate ceramics in the dental market offering excellent esthetics in addition to high flexural strength as well as versatility in their construction technique (either CAD/ CAM or heat pressed), they became the most commonly recommended material for veneers fabrication. [2,3]

It is well known that the clinical longevity of any cemented restoration including laminate veneers depends on many factors mainly the marginal accuracy [4,5]. Marginal discrepancies between the prepared tooth structure and the restorations often lead to leakage of oral fluids beneath the restoration which in turn can cause dissolution of cement, recurrent caries, sensitivity and marginal discoloration. [6,7] In addition to this, marginal adaptation and fit of the veneers influence the resin cement thickness that significantly affects the shade and color of these thin restorations. [8–11]

Vertical distance between the preparation's finish line and the margin of the ceramic veneers is a common definition of vertical marginal gap. [12] Different methods have been introduced for its in vitro measurement as stereo, scanning and transmission electron microscopy, micro-computed tomography (micro-CT) or optical coherence tomography. [13] Each of these methods has its pros and cons that dictate its usage in different situations.

Although various studies showed controversial results concerning the clinically acceptable marginal gap values, yet most of them agreed that a marginal gap between 100 and 120 μm appears to be in the range of clinical acceptance.[14,15]

Since accuracy of dental restorations has been of prime importance for dental practitioners especially in the field of CAD/CAM restorations production, thus various attempts were made to focus on this aspect. The effect of the three basic steps involved in the CAD/CAM procedure on accuracy of dental restorations has been previously addressed in many studies. For example some studies evaluated the different scanning procedures in terms of restorations fitting, [16,17] while others dealt with the designing phase to improve the outcome of fixed prosthesis.

[18] Regarding the third step which is the milling phase, previous researchers evaluated the trueness of available milling devices in the dental market.[19] They found that five axes milling machines yielded significantly better results than four axes milling machines in terms of restorations fitting. Other investigators compared marginal integrity of ceramic copings having different marginal angle designs fabricated by various CAD/CAM systems. They concluded that the different milling processes used in their study had a significant effect on marginal chipping and accuracy of the ceramic restorations.[20]

Due to the increased awareness about the importance of chairside time reduction , thus CAD/CAM latest technologies were developed to provide not only an accurate restoration but also with fast construction technique as the time needed for restoration construction has become valuable to both the dentist and patient.[21] One of these technologies was introduced within the recent softwares which enabled the practitioner to choose from various milling protocols namely the normal, fast and two step milling procedures. The normal milling option is the standard mode that can be used for all materials and indications. If desired , the milling process can be accelerated when using the fast milling option which reduces the grinding time by about 40% as claimed by the manufacturer, enabling the dentist to fit the restoration in a faster period.[22] In the two step milling procedure , the milling time is extended by around 50-60% as it involves 2 steps.[22] First step is for removing excess material by fast mill followed by the second step where the final milling and details of the restoration are accomplished at a regular speed. This option is mainly indicated for milling thin and small restorations as veneers and inlays.

Up till now and according to the investigator's knowledge, the literature still lacks the point of research addressing the effect of different milling protocols on the marginal accuracy of laminate veneers. Thus this study was conducted to evaluate the effect of three different CAD/CAM milling protocols; namely normal, fast, and two-step milling on the peripheral marginal accuracy of glass-ceramic laminate veneers. The null hypothesis of the present investigation was that there would be no difference concerning the marginal accuracy among the three milling protocols

MATERIAL AND METHODS

A total of thirty laminate veneer restorations constructed from IPS e.max CAD glass ceramic were designed and fabricated in this study. The veneers were divided into three groups representing the different milling protocols; ***Group 1:*** Ten veneers constructed using the normal milling protocol, ***Group 2***: Ten veneers constructed using the fast milling protocol. ***Group 3***: Ten veneers constructed using the two-step milling protocol.

I) Acrylic tooth preparation:

A maxillary central incisor acrylic tooth of a Typodont model (NISSIN Dental Model, Koyoto, Japan) was chosen to serve as a die for veneer construction. The maxillary central incisor was scanned before preparation to serve as a biocopy reference of the unprepared acrylic tooth which aids in duplicating the original tooth anatomy during the subsequent CAD/CAM process of veneer fabrication. In order to ensure even and adequate reduction of the typodont, a putty index (Elite HD+ A-Silicone, Zirmack-Italy) was produced for the selected maxillary central incisor acrylic tooth before preparation. Feather edge veneer design was selected in which the facial surface preparation was terminated at the incisal edge without incisal reduction. A standard labial reduction was achieved with 0.3 mm depth for the cervical half and 0.5 mm for the incisal half of the labial surface through using three-wheel diamond depth cutters 0.3 mm and 0.5 mm sequentially (Brassler, USA).

The remaining tooth structure between the depth orientation grooves was removed using a round-end tapered diamond stone (MANI-DIA-Burs-Japan). The preparation was extended proximally just before the contact area. The labial preparation was completed with this tapered diamond, while its tip established the 0.3 mm cervical chamfer finish line 0.5 mm short of the proposed cemento-enamel junction of the acrylic tooth (Figure 1). Finishing of the preparation was done using diamond finishing stones. The sectioned silicone index was used to ensure even reduction. Polishing of the preparation was performed using nylon bristle polishing brush and polishing paste.

Fig. (1) Laminate veneer preparation of maxillary central incisor.

II) Veneer fabrication procedure:

Thirty ceramic veneers were constructed using IPS e.max CAD (IvoclarVivadent, Schaan, Liechtenstein). The restorations construction followed the standard three phases of CAD/CAM process. The scan phase was accomplished using extra-oral scanner “in-Eos X5 scanner” (Sirona dental, Bensheim, Germany). Two scanning procedures were done, one for the original typodont to obtain a bio-copy reference of the unprepared acrylic tooth. The second scan was done to capture digital impression of the prepared tooth. Virtual images of both scans were automatically correlated to aid in restoring the original tooth anatomy during the design phase. The designing phase of the veneers was completed using “Cerec Premium S.W 4.2.5” software. In this phase, veneer parameter was set for 0.5 mm for minimum veneer thickness and 30 μm spacer thickness. Scanning and design were accomplished by the same clinician. Once the design was optimized, it was electronically sent to the milling unit “Cerec MCXL Premium” (Sirona dental, Bensheim, Germany). According to the selected milling protocol, the veneers were divided into three groups: ***Group 1***: Ten veneers constructed using the normal (conventional) milling protocol, ***Group 2***: Ten veneers constructed using the fast milling protocol, and ***Group 3***: Ten veneers constructed using the two-step milling protocol (Figure 2).

Approximate milling time of ceramic laminates of the three groups was as follows: 8 minutes for the normal milling protocol, 5 minutes for the fast milling protocol and 16 minutes for the two-step milling protocol.

After the milling procedure, the veneers were crystallized following the manufacturer’s instruction at temperature of 840 ° C and the dwell time of 7 minutes to give the glass-ceramic its final strength and esthetic properties. Glazing then followed using IPS e.max Ceram Glaze Paste (Ivoclar-Vivadent, Schaan, Liechtenstein) with a standard cooling procedure. Finally, the fit of the veneers was verified on the master preparation (Figure 3).

III) Vertical marginal gap measurement:

For proper assessment of the vertical marginal gap, the veneers were fixed on the master die using one drop of Te-Econom Bond adhesive (Ivoclar-Vivadent) placed centrally in order to ensure adequate yet reversible binding between the die and veneers to stabilize the veneers in their place during the measuring procedure. [23]

Fig. (2) The three tested milling protocols (A), the proposed milling time for the normal milling mode [8.35mins] (B), fast milling mode time [5.08 mins] (C), and the two-step milling mode time [15.57 mins] (D).

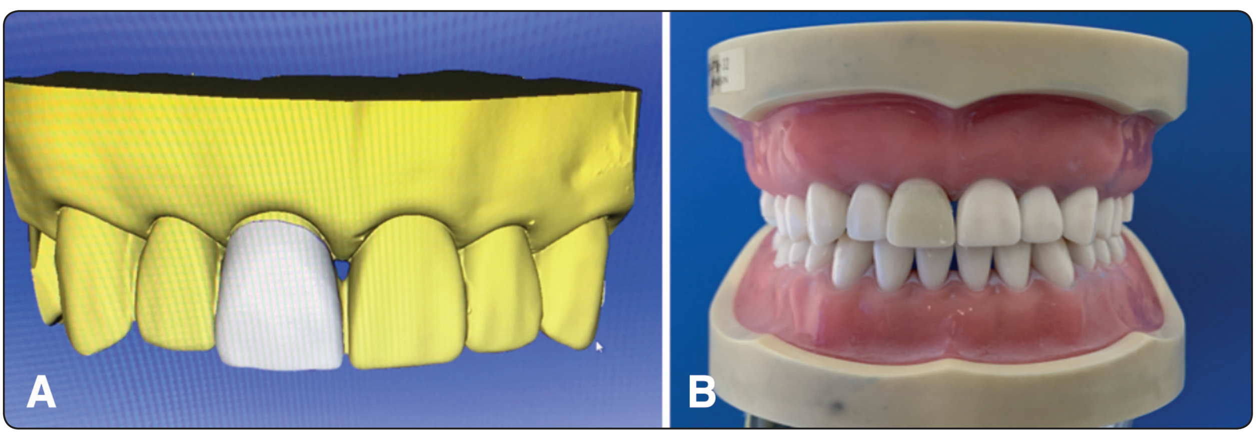

Fig. (3) Virtual design of the labial veneer (A), the milled veneer seated on the master preparation (B)

Each veneer was photographed using measuring Stereomicroscope (Nikon Eclips E600, Tokyo, Japan) connected with an IBM compatible personal computer using a fixed magnification of X 45. A digital image analysis system (Image J 1.43U, National Institute of Health, USA) was used for assessing and evaluating vertical marginal gap width. In this digital software, the measured parameters were expressed in pixels, thus system calibration was done to convert the pixels into real absolute world units. Calibration was done by comparing an object of known size with a scale generated by the image software. Shots of the margins were taken for each veneer. Marginal gap was measured as the vertical distance between finish line of the preparation and the ceramic veneer margin.

The measurements were done along the peripheral circumference for all the veneer margins (mesial, distal, cervical and incisal). Measurement at each point was repeated five times. Then the data obtained were collected, tabulated and then subjected to statistical analysis.

RESULTS

Repeated measures ANOVA results: (Table 1)

The obtained results showed that milling protocol (regardless of surface), surface (regardless of milling protocol) as well as the interaction between the two variables had a statistically significant effect on mean marginal gap. Since the interaction between the variables is statistically significant, so the variables are dependent upon each other.

Effect of milling technique regardless of surface: (Table 2)

Regardless of surface; there was a statistically significant difference between the milling protocols (P-value <0.001, Effect size = 0.625). Pair-wise comparisons between the protocols revealed that there was no statistically significant difference between normal and fast milling techniques; both showed the statistically significant highest mean marginal gap distances. Two-step milling technique showed the statistically significant lowest mean marginal gap distance.

TABLE (1) Repeated measures ANOVA results for the effect of different variables on mean marginal gap

Source of variation	Type III Sum of Squares	df	Mean Square	F-value	P-value	Effect size (Partial eta squared)
Milling protocol	1023.5	2	511.728	14.976	<0.001*	0.625
Surface	684.608	3	228.203	8.725	<0.001*	0.326
Milling protocol x Surface interaction	526.157	6	87.693	3.353	0.007*	0.271

df: degrees of freedom = (n-1), *: Significant at P ≤ 0.05

TABLE (2) The mean (μm), standard deviation (SD) values and results of repeated measures ANOVA test for comparison between marginal gap of different milling techniques regardless of surface

Normal milling		Fast milling		Two-step milling		P-value	Effect size (Partial eta squared)
Mean	SD	Mean	SD	Mean	SD		
40 A	7.5	41.2 A	4.9	33.2 B	6.3	<0.001*	0.625

****: Significant at P ≤ 0.05, Different superscripts are statistically significantly different***

Effect of surface regardless of milling technique: (Table 3)

Regardless of milling technique; there was a statistically significant difference between the surfaces (P-value <0.001, Effect size = 0.326). Pair-wise comparisons between the surfaces revealed that the distal surface recorded the highest mean marginal gap distance with non-statistically significant difference from incisal and mesial surface and with a statistically significant higher mean measurement than the cervical surface which recorded the lowest mean marginal gap distance.

Effect of different interactions on marginal gap: (Table 4 and Figure 4)

Comparison between milling protocols:

At the cervical surface; there was a statistically significant difference between the milling protocols (P-value = 0.009, Effect size = 0.409). Pair-wise comparisons between the protocols revealed that fast milling protocol showed the statistically significant highest mean marginal gap. Normal milling protocol showed statistically significant lower mean value than fast milling. Two-step milling protocol showed the statistically significant lowest mean marginal gap distance.

At the incisal surface; there was no statistically significant difference between the three protocols (P-value = 0.847, Effect size = 0.018).

At the mesial and distal surfaces; there was a statistically significant difference between the milling protocols. Pair-wise comparisons between the protocols revealed that there was no statistically significant difference between normal and fast milling protocols; both showed the statistically significantly highest mean marginal gap distances. Two-step milling protocol showed the statistically significant lowest mean marginal gap distance.

Comparison between surfaces:

With normal milling; there was a statistically significant difference between the surfaces (P-value = 0.001, Effect size = 0.622). Pair-wise comparisons between the surfaces revealed that there was no statistically significant difference between mesial and distal surfaces; both showed the statistically significant highest mean marginal gap distances. There was no statistically significant difference between cervical and incisal surfaces; both showed the statistically significant lowest mean marginal gap distances.

With fast milling; there was a statistically significant difference between the surfaces (P-value = 0.032, Effect size = 0.413). Pair-wise comparisons between the surfaces revealed that distal surface showed the statistically significant highest mean marginal gap distance. There was no statistically significant difference between cervical, incisal and mesial surfaces; all showed the statistically significant lowest mean marginal gap distances.

With two-step milling; there was no statistically significant difference between the surfaces (P-value = 0.133, Effect size = 0.288).

TABLE (3) The mean (µm), standard deviation (SD) values and results of repeated measures ANOVA test for comparison between marginal gap distances at different surfaces regardless of milling technique

Cervical		Incisal		Mesial		Distal		P-value	Effect size (Partial eta squared)
Mean	SD	Mean	SD	Mean	SD	Mean	SD		
34 AB	6.5	37.2 AB	4.6	39.7 A	6.4	41.6 A	8.6	<0.001*	0.326

****: Significant at P ≤ 0.05, Different superscripts are statistically significantly different***

TABLE (4) The mean (µm), standard deviation (SD) values and results of repeated measures ANOVA test for comparison between marginal gap distance measurements of the different protocols and surfaces

Surface	Normal milling		Fast milling		Two-step milling		P-value (Between technique)	Effect size (Partial eta squared)
	Mean	SD	Mean	SD	Mean	SD		
Cervical	33.2 BE	5.6	39.3 AE	3.7	29.4 C	6.2	0.009*	0.409
Incisal	37.3 E	5.1	37.9 E	4.7	36.4	4.7	0.847	0.018
Mesial	44.2 AD	5.8	40.5 AE	2.3	34.4 B	6.3	0.007*	0.421
Distal	45.2 AD	6.9	46.9 AD	3.7	32.6 B	6.7	<0.001*	0.572
P-value (Between surfaces)	0.001*		0.032*		0.133			
Effect size (Partial eta squared)	0.622		0.413		0.288			

: Significant at P ≤ 0.05

A, B, C superscripts in the same row indicate statistically significant difference between techniques

C, D, E superscripts in the same column indicate statistically significant difference between surfaces

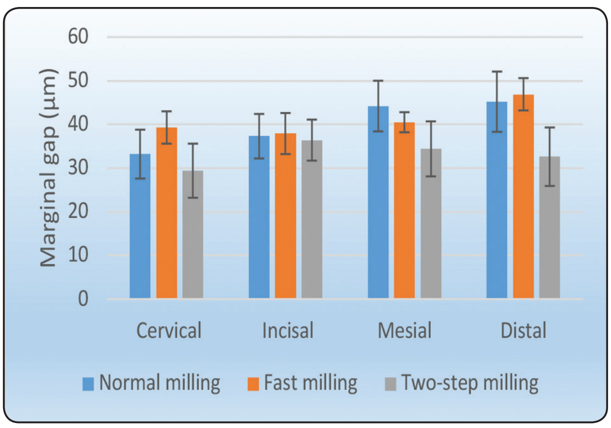

Fig. (4). Bar chart representing mean and standard deviation values for marginal gap distances of the three milling protocols at each surface

DISCUSSION

According to the results of the present investigation, the null hypothesis stating that there would be no difference concerning the marginal accuracy among the three milling protocols had to be rejected since there was a statistically significant difference between the milling protocols .Statistical analysis revealed that both the normal and fast milling protocols showed statistically significant highest mean marginal gap distances while the two-step milling protocol showed statistically significant lowest mean marginal gap distance.

Ceramic laminate veneers are considered among the most conservative approaches to solve many cases having problems in shape, color or alignment of anterior teeth. [24,25]

Lithium disilicate ceramic represents the most preferable material for fabrication of this type of thin and brittle restorations owing to their excellent esthetic and satisfactory mechanical properties. They can be processed using either heat pressing techniques (IPS e.max Press) or CAD/CAM milling procedures (IPS e.max CAD). [26]

Machining of this type of delicate restorations always represents a challenge to the dental personnel specially at critical areas as thin margins. New milling options have been introduced in recent softwares to maximize milling accuracy of ceramic restorations and suit different restoration thicknesses and designs. Since the effect of these milling options on marginal integrity of thin restorations has not been investigated yet, thus this study was conducted to highlight this point of research on laminate veneers with minimal ceramic thickness.

In the current research, a typodont tooth resembling maxillary central incisor was used as it represents the most common tooth in the dental arch restored with laminate veneer. Selection of artificial acrylic tooth was done to overcome any variations in natural teeth which might affect the design and thickness of the restoration [27,28]

In order to duplicate the original tooth contour, a primary scan was obtained for the unprepared tooth to serve as a biocopy reference which was later added to the software during the CAD/CAM procedure to aid in restoration design. [28,29] **Every** effort was done to ensure adequate and even amount of reduction using putty index and depth cutter burs. [27] The typodont preparation followed the guidelines for veneer preparation as stated by many authors to keep the preparation confined within enamel and at the same time ensure enough thickness to provide adequate fracture resistance and proper translucency. [30]

The three milling protocols used in the present study were normal, fast and two step milling procedures. Their selection was based on time factor needed for completion of milling procedure and on the options given by recent software used. The aim was to investigate their effect on the marginal integrity of delicate thin margins of laminate veneer which is considered as an important criterion for success and longevity of the restoration. [31]

Marginal integrity in the current study was assessed by measuring the vertical marginal gap as it is considered as the most frequently used method to examine fitting accuracy of the restoration. [32,33] A high accuracy stereomicroscope was used as a direct view assessment method offering numerous advantages like convenience, accuracy, easiness and speed of use as well as retrievability of restoration unlike other destructive procedures as sectioning method. [34]

Our scope during this study was to examine the sole effect of individual milling protocols on primary precision of the laminate veneers, thus measurements were made without cementation to exclude variations resulting from properties of cement and cementation technique. [35-37]

Measurements were taken along the peripheral circumference for each surface of the veneer (Mesial, labial, distal, and incisal) to obtain an overall picture about the restoration accuracy and seating.

Results of previous researches reported a wide range of vertical marginal gap for laminate veneer restorations, however many articles stated that a marginal gap of 120 μm or less is considered as clinically acceptable. [38-41] Since the marginal results of all groups in the current study ranged from 29.4 μm to 46.9 μm, thus they fell within the clinically acceptable range.

Statistical analysis of the results concerning the effect of milling protocols on marginal accuracy revealed significant difference between them. Two-step milling technique showed the lowest mean marginal gap distance while both normal and fast milling techniques showed the highest mean marginal gap distances. It was apparently logic to obtain these results as the manufacturer demonstrated that two step milling of thin delicate restorations as veneers passes by two stages. The first milling stage is concerned with bulk removal of excess material through fast mill followed by milling at regular speed to obtain fine details of the restoration and this explains the superior marginal accuracy of the restoration compared to the other milling protocols. [22] Since our study was one of its kind using different milling protocols, thus the obtained results were hard to compare with previous or similar studies.

In addition to this, regarding the time taken for each milling protocol, the two step milling lasted approximately double the time needed for the normal milling which might explain the significant difference between them as regards to marginal accuracy .

Irrespective to the milling protocol; the marginal gap distance at the cervical surface recorded the lowest mean marginal gap distance while the distal, incisal and mesial surfaces had the highest mean marginal gap distance. These results were in agreement with previous studies [27,42] which postulated that the least adaptation was incisally. This can be explained by the fact that the margins are thinner incisally, thus more liable for chipping causing gap formation. Also, during milling procedure, the diameter of the cutting tool might be larger than some parts of thin tooth preparations limiting access of the cutting tool to narrow regions as incisal edges leading to incisal misfit. [27] Another explanation might be attributed to lack of incisal edge preparation making it difficult to properly seat the laminate veneer specially in incisal area. [43]

However, these results were inconsistent with other studies [44] showing that the smallest mean vertical gap was noted at the incisal surface, this controversy might be attributed to differences in preparation design, ceramic type and CAD/CAM system used.

A point of concern was whether similar marginal gap values could be achieved if more complicated restoration designs or different materials were selected in this study. Nevertheless, it was the effect of milling protocols on delicate restorations that was of interest for our present study.

One of the limitations of this study was the utilization of an acrylic typodont instead of natural teeth as well as lack of cementation although justification for this was previously discussed. Additional studies must be carried out considering different experimental conditions.

CONCLUSIONS

Within the limitations of this in-vitro study, the following conclusions were drawn:

1) Marginal discrepancy of all groups fell within the clinically acceptable value; thus, the three milling protocols can be safely used.
2) Veneers fabricated using the two-step milling protocol exhibited the least marginal discrepancy among other experimental groups, thus it can be used as the protocol of preference if restoration accuracy is of utmost importance
3) Since there was no significant difference between normal and fast milling protocols regarding marginal discrepancy, thus fast milling can be recommended for veneer fabrication if chairside time is of prime importance in some cases.
4) Cervical marginal discrepancy was observed to have the least value compared to other surfaces

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