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Marginal Accuracy of Conventional and CAD-CAM Manufactured Veneers

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Abstract

The marginal accuracy of porcelain laminate veneer is of great importance for the survival of the restoration. The chemical bond between restorative material and the prepared tooth surface has a direct impact on the success of veneer restoration. Since this bond may be affected by marginal inaccuracies, it is essential that marginal gaps are minimised. Nowadays, the use of digital technology including CAD-CAM systems and digital impression techniques leads to restorations with acceptable margins and tend to limit conventional impression methods and heat press techniques. The purpose of the present review is to investigate the influence of manufacturing techniques (CAD-CAM and heat-pressing) and impression methods (conventional and digital) on the marginal adaptation of lithium disilicate veneers. Both *in vivo* and *in vitro* studies, which fulfilled specific criteria, were included in this study. It was observed that CAD-CAM statistics present promising results with clinically acceptable restorations. Nevertheless, literature lacks *in vivo* studies and the question whether it's time to replace conventional techniques with digital ones is yet to be investigated.

Keywords: *Marginal Fit; Digital Impression; CAD-CAM; Veneers; Heat-Pressed*

Abbreviations

PLVS: Porcelain Laminate Veneers; CAD-CAM: Computer Aided Design-Computer Aided Manufactured; PE: Polyether; PVS-I and PVS-D: Polyvinylsiloxane Imprint and Dimension

Introduction

Nowadays that mechanical properties of dental ceramics have been noticeably improved, esthetics have a distinctive role in patient satisfaction, leading to successful restorations [1]. However, in addition to mechanical strength and esthetics, biocompatibility and marginal adaptation [2] are crucial for the long term survival of restorations.

Based on the available scientific data no clear definition of the gap observed at the marginal area of a restoration existed until 1989, when Holmes [3] suggested that the marginal gap of a prostheses is the perpendicular space from the internal surface of the casting at the marginal area to the margin of the preparation. Nowadays, marginal accuracy of a veneer restoration is measured by the intimate contact between the margins of a fabricated veneer and the prepared tooth. This contact is recommended to be as narrow as possible, because the weak link between the adhesive materials and the tooth and ceramic surface can lead to excessive marginal gap and exposure of the

luting agent. Such marginal discrepancies may lead to gradual dissolution of the cement [4,5], mechanical defects, discoloration, secondary carious lesions, microleakage and plaque accumulation [6,7], resulting in restoration failure.

Therefore, it is essential for the clinician to minimize any inherent risk by creating high-quality, accurate marginal and internal fit between restoration and abutment [8] and veneers do not constitute an exemption. Existing scientific reports on the ideal marginal adaptation of a restoration have not yet come to an agreement. However, several studies support that clinically acceptable marginal gaps should range between 100 and 120 mm, given the advantages that CAD-CAM systems may offer. More particularly, McLean and Von Fraunhofer [9] after examining 1000 restorations during a 5 year period, concluded that a 120 mm marginal gap could provide a satisfying marginal fit of a fixed dental prostheses.

There are many crucial factors that can influence the marginal and internal accuracy of a restoration. Tooth and margin location, preparation design, impression and manufacturing techniques, choice of restoration material, CAD-CAM system and cementation space are some of the multiple factors that play a major role in the survival of the prostheses. Among them, there is a direct interaction between impression and manufacturing technique, choice of material and success of the restoration.

Nowadays, that dental all ceramic prosthetic materials represent the most popular materials used for CAD-CAM restorations, lithium disilicate constitutes a dependable restorative material for indirect fixed prostheses [10]. It provides good esthetics and mechanical strength, as well as satisfying marginal fit. As a result lithium disilicate is a material of choice when it comes to restorations in the esthetic zone. Lithium disilicate blocks used for CAD-CAM systems offers dentists high resistance to fracture, biocompatibility, low material wear and provides them with high optical properties resulting in colors, shades and translucencies similar to the dental structure.

As it comes to impression and manufacturing techniques, it is presumed that the use of CAD-CAM systems can eliminate marginal discrepancies due to the advantages deriving from digital technology. On screen magnification, study and processing of scanned dental arches would provide dentists and dental technicians with valuable tools in order to re-examine a dental impression. Moreover, the precision of the milling machine and the existence of high definition intraoral cameras can reduce chairside time and eliminate the mistakes occurring by traditional impression and manufacturing procedures. It may also offer the ability to immediately transmit the data collected to a dental laboratory.

Purpose of the Study

The purpose of this review is to investigate the influence of manufacturing techniques (CAD-CAM and heat-pressing) and impression methods (conventional and digital) on the marginal adaptation of lithium disilicate veneer.

Materials and Methods

Literature search was conducted using the electronic databases PubMed and Google Scholar with the year limits of 1991 onwards to the update of 2019. Key words were: "veneer marginal fit/marginal discrepancy/marginal gap/digital impression", and "CAD/CAM marginal fit/gap/accuracy/discrepancy", "press marginal fit/gap/accuracy/discrepancy". Only articles published on international and scientific journals have been included to the study. Both *in vivo* and *in vitro* studies were selected. Criteria used for inclusion were: randomized and non-randomized controlled clinical trials, *in vitro* mechanical behavior tests, systematic reviews, meta-analyses, cohort studies and case-control studies. Case studies, letters of opinion, articles lacking scientific evidence or motivated by commercial interests have been rejected. Criteria used for quality assessment of the included studies were: type of study, type of ceramic material, type of impression technique, methods of measuring marginal discrepancy, type of fabrication technique. A total of 30 articles were selected and incorporated in this study. Measurements had to match the description provided by Holmes [3] for either the marginal gap or the absolute marginal discrepancy.

Measurement methods

Many techniques have been used in several studies to document the accuracy of a dental prostheses and this may have a significant impact on the variation of their results [10]. The most widely used method involves direct microscopic examination of the marginal area. Unfortunately, this method comes with two major disadvantages. Firstly, it is difficult to identify the exact reference points in order to make the measurements. Moreover, this technique may lead to projection errors [11,12].

The silicone replica is a technique that relies on measuring the thickness of low viscosity silicon impression material used in place of the resin cement between the die and the fixed prosthesis [13-15]. The light-bodied silicone replica of the gap is then sectioned, and the zone that corresponds to the marginal area is observed at magnification using a microscope. This method offers the advantages of being non-destructive [13] with high reliability and validity as suggested by several authors [16,17]. However, measurement of adaptation from the replica with a light microscope provides only 2D data and its interpretation can be difficult if the gap is located subgingivally [18,19].

Last but not least, x-ray microtomography is an innovative and non-destructive technique, which delivers 2-dimensional and 3-dimensional imaging of the internal and marginal gap. X-ray microtomography provides close sections of the area, allowing for a great number of measurement sites and easy recognition of the critical distances.

Results

Conventional versus digital impressions

Conventional impression constituted for years the ''golden standard'' for dental restorations. However, modern dentistry imposes the need for less clinical and laboratory steps in order to reach the final restoration. Complicated procedures, including multiple sensitive steps, may undoubtedly lead to less accurate impressions [20]. The impression material and tray used, the impression protocol, the disinfection liquids, the type of gypsum, the human factor and compliance with the time limits imposed by each manufacturer are some other factors which may influence impression accuracy [21]. By following a digital protocol, the impression and manufacturing procedure is simplified, as the multiple steps are eliminated, and can be more easily controlled. Time limits imposed by some impression materials, land transport time and patient discomfort caused by the conventional impression procedure are some negative factors which could be avoided with digital technology [22]. Nevertheless, application of intraoral scanning impression techniques cannot be executed under specific clinical circumstances of highly reflecting surfaces, deep subgingival preparations with complicated tissue management, moisture, bleeding and patient movement.

Runkel., *et al.* [21] studied the influence of the scanned surface (impression or gypsum cast) on the accuracy of the data obtained by two different scanners, applying the parameters of trueness and precision [23]. Runkel used 3 different materials (polyether-PE, polyvinylsiloxane imprint- PVS-I and polyvinylsiloxane dimension- PVS-D) and customized trays to take impression of the specimen and then scanned the surfaces using two desktop laboratory scanning systems (D810 and Zirkonzahn desktop scanners). Twenty-four hours after taking the impression, the impressions were poured using scannable type IV gypsum, sectioned in order to receive master models and then rescanned. Considering the scanning devices D810 showed significantly better performance with PVS-I and PVS-D than the Zirkonzahn desktop scanner. As for the PE group, both scanners performed similarly. Furthermore, in view of the impression, PE and PVS-I performed better, regarding trueness and precision for most groups, than PVS-D. However, all marginal values were within an acceptable range for clinical use. Finally, regarding the scanning objects, significant differences found in marginal adaptation were attributed to both desktop scanner performance and to the impression material. In view of the D810 scanner, better trueness was noted for scanning the cast with PVS-I and the impression with PVS-D. For the Zirkonzahn scanner better trueness was found when scanning the impression taken by PE or PVS-I. These results seem to agree with the results found by Matta., *et al.* 2016 [24], supporting that scanning the impression itself exhibit better marginal adaptation than scanning the cast in a laboratory using a non-contact scanner. There are current studies supporting the accuracy of desktop scanner impressions without the intermediate conventional steps, in which marginal adaptation is within the acceptable range for clinical use [25-27]. However there are significant limitations in the full digital workflow such as deep

undercuts and small diameters making the accessibility of optical scanning devices difficult to parts of the impression due to shadowing, especially when the scanning device is based on triangulation technology [21].

Guzelian., *et al.* [2] in an *in-vitro* study compared the marginal integrity of anterior lithium disilicate veneers, fabricated with a full digital technique (Lava COS and CAD/CAM) and with conventional methodology (PVS impressions and IPS emax press). In addition, Guzelian evaluated the gap distance ranges of digitally impressed against conventionally impressed veneers. All marginal values were assessed considering 120 μm as the maximum and acceptable clinical indicator. In total, 20 lithium disilicate veneers were fabricated with both conventional and digital methods. In the first group, ten conventional silicone impressions were taken using custom trays and poured with Type IV die stone and ten monolithic lithium disilicate veneers were fabricated with the traditional IPS emax heat-press technique. For the second group ten digital impressions were taken using Lava COS scanner. Data were sent to a laboratory where veneers were virtually designed, prepared and fabricated using IPS e.max CAD/CAM with lithium disilicate glass-ceramic blocks. Marginal accuracy was measured by visual observation using a stereomicroscope under 45x magnification. The results of this study demonstrated that digital impressions exhibited statistically significant inferior marginal accuracy at all locations and were three times more likely to present gap distances greater than 120 μm, compared to conventional impression method. Considering a marginal gap value less than 120 μm as clinical threshold of good fit, digital impressions presented only one average good fit at the mesial location. On the other hand, conventional impressions demonstrated marginal fit values significantly less than 120 μm at three orientations, the one exception being the distal location.

Heat-press versus CAD/CAM technique

Heat press technique consists one of the most common fabrication techniques for all- ceramic restorations. It can be applied in the manufacturing of single-unit crowns, inlays, onlays, and veneers [28]. A wax pattern, similar to the final restoration, is created and pressable ceramics are then infused under controlled pressure in a special designed press oven. The use of wax pattern method leads to a satisfying control of the internal and marginal accuracy of the restoration.

On the other hand CAD /CAM systems offer a less time consuming alternative (no need for manufacturing of casts and mounting) on a lower cost. Moreover, disinfection of the impression, pouring of stone, application of die hardener and die spacer, scaling during wax-pattern fabrication and investment are some procedures that can cause possible marginal inaccuracies. The possibility of a human error and the temperature variations are also variables that can possibly cause dimensional alterations [29-34].

There have been many *in vitro* studies evaluating the influence of veneer fabrication method on marginal adaptation [35-39]. Aboushelib., *et al.* [36] in an *in vitro* study documented that in the pressable PLVs group marginal discrepancies, both in vertical and horizontal axis, as well as internal discrepancies and microleakage, showed significantly lower values than in the CAD-CAM groups. In this study Aboushelib investigated whether the fabrication technique has an impact on the internal adaptation, marginal accuracy and microleakage of ceramic laminate veneers. Forty conventional polyvinylsiloxane impressions were made and after the investment and the burn out, 20 heat pressed ceramic laminate veneers were fabricated. Accordingly, after incisal, labial and palatal scanning of the 20 non-waxed gypsum dies, 20 machinable laminate veneers were fabricated. All 40 veneers were subjected to artificial ageing, before sectioned and examined at a stereo microscope. Significantly higher marginal discrepancy values, especially at incisal and cervical margins, were observed at machinable ceramic group rather than at pressable ceramics. Machinable ceramic veneers presented also high film thickness measurements. The author supports that this differences occurs because the wax up pattern procedure gives the opportunity to form the shape and the marginal sealing of the restoration as they are built directly on the prepared working model. Moreover, Martin., *et al.* 2000 [40], suggests that CAD/CAM restoration have greater marginal inaccuracies as the imaging software has limitations in scanning, designing and processing imaging data for the analysis of the marginal line. Finally, Aboushelib concluded that apart from better marginal adaptation [37,38,41] pressable veneers present lower and even cement thickness, coming in agreement with current literature [42]. However, a recent study regarding CAD/CAM restoration for implants showed better marginal fit for machinable restorations [43]. In addition, Al-Dwairi., *et al.*

[39] examined *in vitro* the influence of fabrication technique (CAD/CAM or heat-pressed) and type of composite resin cement on the marginal and internal accuracy of porcelain laminate veneers. Forty composite resin dies were fabricated and 20 of them were restored with veneers made from a feldspathic glass ceramic using the lost-wax and heat pressed techniques. The second half included 20 veneers fabricated from a fine-structure feldspar ceramic using a CAD-CAM milling machine. Ten veneers from each group were cemented to their dies with two different resin cements accordingly. Examination of the specimens with scanning electron microscope showed that fabrication technique and the type of luting agent significantly affected the marginal fit of the prostheses and that marginal gap was found higher at the incisal aspect than at the cervical position. As reported in other studies, Al-Dwairi., *et al.* noted that the heat-pressed restorations appear to have greater marginal accuracy than those fabricated using CAD-CAM technique. Finally, Al Dwairi concluded that the type of ceramic material, its fabrication technique, the type of composite resin cement and the location of the marginal gap have a statistically significant influence in the mean marginal and internal discrepancy values.

Fadhil, 2017 [44], in his *vitro* study investigated the influence of veneer preparation design (butt joint incisal reduction or overlapped incisal reduction with palatal chamfer design) and manufacturing technique (pressable or machinable) on marginal and internal adaptation of ceramic laminate veneers. Four groups of lithium disilicate laminate veneers were included in the study (Group I: prepared with butt joint incisal reduction design and restored with IPS e.max CAD, Group II: overlapped incisal reduction with palatal chamfer design restored with IPS e.max CAD, Group III: butt joint incisal reduction design restored with IPS e.max press, Group IV: overlapped incisal reduction with palatal chamfer design restored with IPS e.max press) and evaluated via the silicone replica technique and a digital microscope. Statistics of the marginal, internal, and total gaps showed that the fabrication technique had a highly significant effect on marginal gap ($p = 0.00$), no significant effect on internal gap ($p = 0.30$) and significant effect on total gap ($p = 0.02$). According to the statistics, pressable ceramic groups showed significantly higher gap values. As a result, there is an interaction between the fabrication technique and the marginal accuracy, as Jha., *et al.* [45] also presented in his study. However, these results disagree with other studies mentioned above, Al Dwairi and Aboushelib [36,39] supporting that the pressable ceramic veneers demonstrated significantly lower marginal and internal gap values compared to CAD/CAM ceramic veneers. On the other hand, the preparation design showed significant effect on marginal gap ($p = 0.02$), no significant effect on internal and total gaps ($P > 0.05$). The marginal discrepancy recorded incisally (incisal margin and incisal area internally) in comparison with the marginal adaptation in other areas, comes to an agreement with the study of Suh., *et al*. [46] who noted that the least adaptation was incisally. Totally, the heat-pressed ceramic veneers with overlapped incisal reduction design demonstrated significantly higher marginal gap, concluding that the fabrication technique and the preparation design play a distinctive role on the marginal accuracy of a ceramic veneer. Nevertheless, marginal and internal gap values reported in the present study were higher than the suggested acceptable values [47].

Regarding the *in vivo* literature, Yuce., *et al.* [48] examined the long-term influence of manufacturing technique on the marginal and internal adaptation of porcelain laminate veneers (PLVs). The manufacturing techniques tested were the heat pressed and the CAD/CAM technique and the follow-up period lasted 2 years after the cementation procedure. Twelve patients participated in the study, all restored with 61 PLVs (30 pressed and 31 CAD/CAM PLVs). For the heat-pressed group (HP) silicone impressions were taken and wax-patterns were fabricated manually before the investment and a fully digital protocol was followed in CAD/CAM group. All specimens were observed and assessed via the silicone replica technique and a light optical microscope. After cementation, evaluation was conducted at baseline (immediately after cementation), 6, 12, 18 and 24 months using the modified USPHS criteria [49,50]. As for the marginal and internal adaptation there were no statistically significant differences between the two groups ($p = 0.541$ and $p = 0.734$ accordingly) however marginal adaptation values were higher than the internal adaptation values. During the follow-ups, both groups presented 100% survival rates of their restorations and they had no significant differences between the ratings. As a result, Yuce concluded that the manufacturing technique does not have an impact on the marginal and internal adaptation of a PLV and that both heat-pressed and CAD/CAM veneers were acceptable. However, although the majority of short- and long-term clinical investigations showed clinically satisfactory results of porcelain laminate veneers [51-53], significantly decreased survival rates were observed at 5 to 10 years of service [54].

Nejatidanesh., *et al.* [55], in their *in vivo* study manufactured 197 laminate veneers for 72 patients; all restored vital teeth. Restoration were digitally designed with, milled from e.max Cad or IPS Empress CAD and luted with a light curing composite. The restorations were assessed by Modified CDA guidelines [56]. The results of this study (99.0%) come to accordance with other recent systematic reviews (88% to 95.7%) concerning the 5 - 10 year survival rate of laminate ceramic veneers [57,58]. As for CAD/CAM fabrication Wiedhahn., *et al.* reported 96.9% survival rate for CAD/CAM laminate veneers after 5 years [59]. In this study Nejatidanesh., *et al.* reported that regarding marginal adaptation of the veneers there was no significant difference neither between the first and the fifth year ($p = 0.07$, $p = 0.41$ for Empress CAD and e.max CAD respectively) nor between the two materials used ($p = 0.09$). A recent study of Gurel., *et al*. [60], also showed good marginal accuracy of all porcelain veneers. Other *in vivo* studies also reported satisfying results and a good periodontal response in marginal fit of 65 - 98% ceramic laminate veneers [61,62]. Finally, Nejatidanesh concludes that although all restorations were clinically acceptable, emax CAD veneers had significantly higher success rate than Empress CAD veneers.

Wax-up/pattern manufacturing techniques

As for the pattern manufacturing techniques Seen-Young Kang., *et al*. [63] support that manufacturing methods can replace the traditional free-hand wax technique at their *in vitro* study which analyzed the marginal discrepancy of lithium disilicate ceramic veneers manufactured with heat-press technique using three different methods: traditional wax-up (TW) and CAD-CAM additive (AM) and subtractive(SM) methods. Ten patterns were fabricated from each group, a total of 30 patterns. As a result, thirty lithium disilicate ceramic veneers (IPS e.max Press LT, Ivoclar Vivadent, Schaan, Liechtenstein) were then fabricated using the heat-pressed technique. A silicone replica technique was used to measure the marginal discrepancy. Marginal gap was measured in twelve areas which were designated and cross-sectioned by dividing the silicone replica mold into buccal, lingual, distal, and mesial areas, on a total of 360 points using a digital microscope. In the labial area the samples of the TW group presented the largest discrepancy (90.74 ± 47.61 μm), while the SM group presented the lowest (65.96 ± 24.34 μm). Accordingly, in the distal area the AM group presented the highest values (86.87 ± 17.09 μm), while the TW the lowest (63.93 ± 33.84 μm). In the mesial and lingual areas, the AM group presented the highest values (101.79 ± 25.09 μm, 119.32 ± 29.46 μm) and the AM the lowest (81.12 ± 29.43, 76.60 ± 28.76 μm). Totally, the AM group had the largest mean values (99.68 ± 28.01 μm) of the three groups, followed by the TW and the AM groups. The deviations found are of statistical significance and exist within the allowable limit of less than 120 μm.

Discussion

Recently, several aspects of CAD/CAM systems presented significant technological improvements. These include the development and application of new materials, the introduction of virtual articulator software, and development of scanners, the availability of more efficient milling and 3D printing machines, and transfer of digitized casts to the virtual articulator. However, the introduction of full digital workflow in everyday practice is still expensive compared with the conventional one. However, the current literature on digital impressions showed promising results.

There is a direct relation between the scanning system and the scanned impression material, with some systems reacting in a better way with specific impression material. Nevertheless, all accuracy measurements seem to be clinically acceptable. There are also some researches supporting that scanning dental impressions lead to more accurate restorations than scanning casts. Currently, there is a lack of studies comparing the accuracy of the partially digital workflow by the digitalisation of modern impression materials using different laboratory scanning devices. Also, to the best of the author's knowledge, there are few studies comparing the accuracy of the resulting datasets when the impression itself is scanned versus the well-known procedure of gypsum cast digitalisation [21]. Moreover, the precise influence of scanning powder is yet to be determined. Regarding to the higher marginal deficiency values for the digitalization of the impression, the applied scan spray could have been a possible cause of error [21]. Thus, it is essential that impression materials which may be digitized without applying a scanning powder, should be investigated in future researches.

On the other hand, most *in vitro* studies examining restorations manufactured following a full digital protocol, presented better marginal accuracy compared to restorations where conventional impression method in combination with heat-press technique were fol-

lowed. Measurements in these studies usually refer to veneer restorations which were not cemented and none of them had undergone ageing procedure.

Moreover, the higher gap values of pressable ceramic veneers found in current *in vitro* literature may be attributed to the sensitive nature of the pressing technique. The success of the fabrication of a heat-press veneer is significantly depended on technician skills, delicacy and experience. Moreover, wax-pattern technique pose many risks including elastic memory, thermal sensitivity, and a high coefficient of thermal expansion [64]. Furthermore, porcelain shrinkage and the grit blasting during divestment can produce microcracks and chipped margins resulting in marginal inaccuracies [65]. As for the CAD/CAM groups, the higher values of gap incisally may related to the diameter of cutting tool that may be larger in diameter than some parts of the tooth preparation, such as the inner surface of the incisal edge causing misfits incisally [36]. Virtual-to-manufacturing limitations are common when sharp, abrasive diamond-cutting instruments become compromised from heavy, previous usage, causing marginal chipping of ceramic material. Since veneers demand a scrupulous geometric reduction, any shortcoming in these manufacturing steps affect the delivered marginal integrity of digital casts.

In vivo studies support that manufacturing technique does not affect marginal adaptation and full digital protocols lead to acceptable restorations which are fatigue resistant. The fabrication technique, preparation design and the material may have an influence on the marginal adaptation of the restoration. Present literature though lacks in studies comparing the marginal fit of veneer restorations manufactured with conventional heat-press technique and CAD-CAM technology using lithium disilicate as restorative material.

To sum it up, all these findings support the results of the present study, suggesting that a digital workflow requires substantial improvements preparation, design, and milling in order to compete with a conventional workflow involving PVS materials. Despite the fast industrial progress, there seems to be a lack of scientific *in vivo* evidence in the field of complete digital prosthodontics workflows [66]. As a consequence, there still remains the question for clinicians and dental technicians, whether to invest and implement complete digital workflows in their dental routines.

Conclusion

Based on the findings of this review, the following conclusions were drawn:

1. Conventional impressions show significantly higher values of marginal accuracy compared to digital impressions. There are significant limitations in the full digital workflow such as deep undercuts and small diameters making the accessibility of optical scanning devices difficult to parts of the impression.
2. Scanning the impression itself exhibit better marginal adaptation than scanning the cast.
3. Regarding the manufacturing techniques both heat-press and CAD/CAM methods resulted in clinically acceptable restorations.
4. The type of ceramic material, its fabrication technique, the type of composite resin cement, the preparation design and the location of the marginal gap have a statistically significant influence in the mean marginal and internal discrepancy values.
5. Digital workflows seem a promising alternative to conventional techniques, in order to achieve more accurate and better esthetical restorations. Nevertheless, further *in-vivo* research on these methods needs to be performed.

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