Accuracy and Reliability of Methods to Measure Marginal Adaptation of Crowns and FDPs: a literature review

Abstract: Purpose: To review methods used to investigate marginal adaptation of crowns and fixed dental prostheses, and discuss testing variables employed and their influence on results. **Methods:** Online libraries including PubMed, Scopus and Ovid, were searched for articles evaluating the marginal adaptation of crowns and FDPs using combination of keywords:“marginal accuracy”, “marginal fit”, “marginal gap”, “marginal discrepancy”, “fitting accuracy”, “crown” and “FPD”. Peer-reviewed publications in English in the period 1970 to December 2011 were collected, evaluated by their abstract, and included if they met the inclusion criteria. The criteria involved studies evaluating marginal adaptation of crowns and fixed dental prostheses through clear experimental protocols. Exclusion criteria involved longitudinal prospective and retrospective clinical evaluations, studies using subjective tactile sensation; and other predefined criteria. **Results:** 277 papers were identified and only 183 met the inclusion criteria. Direct view technique was used by 47.5% of the articles followed by cross-sectioning (23.5%) and impression replica (20.2%) techniques. The marginal gap values reported by these techniques varied among individual crown system and across different systems because of variations in studies type (*in-vivo* vs *in-vitro*), sample size and measurements per specimen, finish line design, and stage at which the marginal gap was measured. **Conclusion:** There was a substantial lack of consensus relating to marginal adaptation of various crowns systems due to differences in testing methods and experimental protocols employed. Direct view technique was the most commonly used method of reproducible results. Also, conducting an experimental set-up of testing a minimum of 30 specimens at 50 measurements per specimen should produce reliable results. Additionally, using a combination of two measurement methods can be useful in verification of results.

Index words: Crown fit, marginal fit, FDP fit, fitting accuracy.

Introduction

Fixed dental restorations mainly aim to restore function and aesthetic of lost intra-oral structures without jeopardizing the oral or general health of the patients [1]. Ill-fitting restoration is potentially harmful for abutment teeth and supporting periodontium. It provides access and host for oral bacteria adherence which can possibly cause secondary caries and /or traumatic gingival irritation [2, 3]. Micro leakage through the dentinal tubules to the pulp chamber may lead to endodontic inflammation [4, 5]. In addition, the restoration itself can be affected by the poor margin as variation in the fitting can create stress concentrations which may reduce the strength and long-term success of the restoration [6].

Clinically acceptable marginal gap of fixed restorations is difficult to be precisely identified through the literature. American Dental Association (ADA) specification No.8 [7] indicates that the thickness of luting cement for a dental crown should not exceed 25 µm when using type I luting agent or 40 µm when using type II luting agent. Although, marginal openings in this range are seldom achieved; it has been considered a clinical goal [8]. Christenson G (1971) agreed with the ADA specification [9]; others suggested modifying it. Fransson et al. [10] and Mclean et al. [11] argued that the clinically acceptable marginal gap after cementation should be less than 150 µm and 120 µm respectively. Additionally, Mclean et al. [11] examined the marginal fit of 1000 fixed restorations over a 5 years period and indicated that marginal gap less than 80 µm is difficult to detect under clinical conditions.

Till this date, there is no conclusive evidence of optimum fit of contemporary ceramic systems. This topic is heavily investigated and fit values reported are widely diverse and range (in µm) from 7.5 to 206.3 [12, 13]. Such variation can be mainly attributed to lack of coherence about the definition of “fit” [14, 15], along with differences in methods employed to determine the fit [16-21], testing parameters followed [8, 13, 20, 22-29] and ceramic systems investigated [12, 23, 30-33].

Holmes et al. defined the internal gap as the measurement between the axial wall of the prepared tooth and the internal surface of the casting, while the same measurement at the margin is called “marginal gap” [34]. Furthermore, an angular combination of marginal gap and extension error is an “absolute marginal discrepancy” which specifically defines the linear distance from the surface finish line of the preparation to the margin of the restoration [34]. It is considered the best alternative measurement since it always be the largest error at the margin and reflects the total crown misfit at that point, both vertically and horizontally [34]. Measuring methods are different as they mainly span two approaches; invasive and non-invasive as in sectioning and direct view techniques respectively. Experimental set-ups can differ at the stage of testing the fit such as before or after cementation and involve other variables (i.e. sample size, measurements per specimen). Furthermore, ceramic systems differences in construction techniques (i.e. CAD/CAM, cast and Slip ceramics) can affect the restoration fitting accuracy [13, 15, 35-38].

A review paper published in 2010 reported the significance of some variables on the fit accuracy of fixed dental prostheses (FDPs) made of zirconia-based ceramics [39]. However, literature still lacks comprehensive review of most variables affecting the fit of wider range of available ceramic systems in contemporary dental practices. Therefore, the aim of this study is to review methods used to investigate marginal adaptation of crowns FDP, discuss testing variables employed and their influence on results. It covers all commonly used ceramic systems nowadays whether conventional or CAD/CAM and highlight all variables that affected accuracy of marginal gap measurements reported.

Methods

Online search using libraries including Medline, Scopus and Ovid, to identify published works evaluated the fitting accuracy of indirect dental restorations, was conducted. Peer reviewed works published in English language in the period 1970 to December 2011 were only considered. The search was carried out using combinations of the following key/mesh words and phrases: "marginal accuracy", "marginal fit", "marginal gap", "marginal discrepancy", "precision of fit", "fitting accuracy", "crown", "bridge", "FPD". The articles were initially evaluated by reading their abstracts, and further reviewed if they met the required inclusion criteria. The criteria included studies evaluating the fitting accuracy of any crown system through clear methodology and experimental conditions. *In vitro* and *in vivo* studies evaluating the fitting of any metal, metal-ceramic (MC), all-ceramic crown systems or crowns and FDPs made out of polymers as in all-polymer restorations (i.e. Fiber Reinforced Composites) through gap measurement were included. Exclusion criteria included:

i. Longitudinal prospective and retrospective clinical evaluations as they depend on a subjective evaluation according to dentists' or patients' satisfaction,

ii. Studies evaluated the marginal fitting through subjective tactile sensation; and

iii. Studies evaluated the internal fitting without reporting the marginal gap.

The selected articles were reviewed and grouped according to their methods as follows: 1. direct view technique, 2. cross-sectioning technique, 3. impression replica technique, and 4. other methods. An in-depth consistent, clear and comprehensive analysis was generated to summarize the experimental variables among the studies, which could have influenced their reported results.

The analysis included:

- Article demography (publication year, authors and the type of restoration tested),
- Method of gap measurement,
- Type of study (*in vivo* or *in vitro*),
- Sample size,
- Number of measurement per specimens,
- Finish line design,
- The stage at which the measurements were performed
  1. Before or after cementation,
  2. Before or after porcelain firing
- The marginal gap recorded

Results

The electronic search collectively revealed 277 articles; of which only 183 studies processed for review. The 94 articles did not meet the criteria were 66 studies of prospective or retrospective clinical evaluations, 6 studies did not mention all the required information about the measurement technique they used, 6 studies evaluated the fitting accuracy through the modified USPHS (United States Public Health Service) criteria and tactile sensation, 7 studies measured the internal fit only, and 9 studies evaluated the fit of partial crowns.

Generally, there was no conclusive evidence on the best methodology to evaluate the fitting accuracy of crowns and FDPs. A variety of methods and testing parameters have been used for this purpose including mainly direct view, cross-sectional view, and impression replica technique (Table 1). Furthermore, direct comparisons between studies were not possible as studies varied in their types (*in vivo* vs *in vitro*); sample size and number of measurements per specimen; preparation and finish line design; and when the gap was measured. Marginal adaptation varied among conventional and CAD/CAM ceramic systems as shown in Table 2.

(Insert tables 1 and 2)

Discussion

Influence of measurement method

As shown in Table 1, six methods are used. Of which direct view technique, was the most commonly used with 47.5% followed by cross-sectioning method (23.5%) and impression replica technique (20.2%). Direct view technique measures the gap between crown and die at the margin but not internally using microscope at different magnifications. This method does not incorporate any procedures on the crown-die assembly such as sectioning or replications of the cement space before measuring the gap; hence making it cheaper and less time-consuming than other techniques and reduce the chance of error accumulation that may results from multiple procedures and ultimately impact the accuracy of results. However, this method can only be used *in vitro* as it requires direct examination of marginal gap under high power microscopy, which is crucial for the accuracy of this method. It has been reported that Scanning Electronic Microscopy (SEM) imaging was better than light microscopy to evaluate marginal gap of class II CAD/CAM inlays [195]. However, Groten et al. [53] reported, no significant difference between the accuracy of the two techniques, although according to the authors, SEM was able to provide more appropriate and realistic observations than a light microscope particularly with complex margin morphologies. Other microscopes used included digital microscopes [33], stereomicroscopes [55] and travelling microscopes [70]. They provided limited results from widely separated measuring points, hence calculated means usually demonstrate large standard deviations, and the results reported might be questionable [169].

Additional disadvantages include difficulty in selecting the points where the marginal opening is to be measured [178], inability to differentiate between tooth structure and tooth–coloured cement or identifying the most apical part of the preparation margin [127]; margins of the crown and die may appear rounded when viewed under magnification [178].

In the impression replica technique, however, the crown is filled with low viscosity light body silicone material and seated on the die simulating the cementation procedure. After setting of the silicone material, the crown is gently removed from the die, and heavy body silicon is injected inside to stabilize the thin light body film before removing it from inside the crown. The light body silicon layer can then be sectioned and measured at different sites. Few researchers [22, 23, 31, 35, 154, 178, 179] carried out some modifications on the impression replica technique by making external impression of the marginal gap after fixing the crown to its corresponding die. The impression was then poured with epoxy resin material and marginal gap was measured on the epoxy resin model. However, the impression replica technique has its constraints and inherent errors such as difficulty in identifying the crown margins and finishing lines, tearing of the elastomeric film upon removal from the crown [23], and mistakes in sectioning plane can lead to overestimated measurements [156]. Laurent et al. [196] found that if appropriate silicon is used, the cement space may be replicated and its thickness measured regardless of the localization. Similarly, Rahme et al. [191] reported no significant difference between silicon replica technique and sectioning technique in measuring the marginal gap of Procera crowns and advocated that using low-viscosity silicon for the replica technique can imitate the film thickness of a cemented crown applying glass ionomer cement.

The cross-sectioning method allows for direct measurement of the cement thickness and marginal gap in the vertical and horizontal planes; minimising chances of software or repositioning errors [182]. It also permits uninterrupted view of marginal gap adjacent to the connector in fixed dental prosthesis specimens [120]. However, this method does not allow long-term analysis and comparison of the results before and after different manufacturing stages using the same specimens [192] and the number of measurements is limited to the plane of sectioning which might not represent the complete fit of the crown [186].

Profilometry, on the other hand, is a nondestructive method. It presents the view of both the die and the specimen in the same focal plane on monitor, thus allowing for an accurate focus [24]. However, with profilometry, the thickness of the cement layer at the marginal areas can only be indirectly inferred, and in the case of sequential analysis, extreme care should be taken in repositioning the specimens, otherwise re-profiling discrepancies will occur [182]. Remaining methods including; Digimatic micrometer and Micro CT scan attracted least attention mainly due to inherent technical difficulties.

Cross checking gap measurements among these methods yielded great variances even within the same ceramic system as shown in Tables 1 and 2. For example, the marginal gap of In-Ceram Alumina crowns as reported in the literature ranges from 7.5 to 161 µm [13, 33]. The significant differences in the techniques and variables used in the two studies could be an acceptable explanation of this wide range which might not reflect the actual fit of the restoration. However, comparing the results of similar studies [24, 25], which used almost the same technique and variables to measure the marginal gap of In-Ceram Alumina crown; reveals that the marginal gap of this crown system is 57 µm and 49.8 µm respectively. Both Balkaya et al [24] and Quintas et al [25] used profile projector and measured the marginal gap under similar condition (except the number of measurement per sample), and their results were comparable. The marginal gap of In-Ceram Zirconia (slip casting) FPD framework represents another example that shows how using different methods for measuring the marginal gap can influence the results. The marginal gap of this system was reported as 25 and 113 µm [30, 38]. Although the two studies used same experimental set-ups, the methods of gap measurement were different; direct view technique and sectioning methods were used respectively. It is noticeable that the results reported do not offer information about the actual fit of this Zirconia system. Furthermore, Komine et al [181] and Marties-Rus et al [36] reported inconsistent results of In-Ceram Zirconia system (Vita YZ, Cerec inLab) when using replica technique (91.6 μm) and direct view (12.4 μm) techniques respectively.

Some studies used combinations of two methods; namely silicone replica and cross-sectioning methods [191-194] and results were not conclusive. Tsitrou et al [193] used this combination to measure the marginal gap of Cerec crown. They reported mean marginal gaps on chamfer preparation (in um) of 94 and 91 and on shoulder preparation 91 and 77 when using silicon replica and cross-sectioning techniques respectively. Shearer et al [192] reported statistically significant differences in marginal gap of In-Ceram system when using sectioning and silicone replica techniques (8.3 and 28.6 um respectively). They advocated the accuracy of the sectioning technique above the silicone replica. However, Rahme et al [191], did not report significant differences between the above methods for Procera copings as marginal gap reported was 31.9 and 33.6 using sectioning and silicone replica techniques respectively.

Influence of experimental set-up

Researchers used different experimental set-ups and measured the marginal gaps under different conditions. Making the measurement *in vivo* or *in vitro* [50, 170, 182], before or after cementation [22, 23, 31, 148], before or after veneering [20, 24, 166], on a chamfer or shoulder finish line [13, 25, 152], sample size and number of measurement per sample [63, 106] have been found to affect the marginal adaptation. Hence, differences in setting these conditions have led to inconsistencies in the results leading to conflicting conclusions concerning the clinical acceptability marginal fit of specific ceramic systems. The same crown system might be considered as having a perfect marginal fit according to one study and having clinically unacceptable fit according to another. Table 2 shows the highest and lowest marginal gap values of various crown systems as reported in the literature.

Clinically, several factors such as tooth preparation, impression technique and cementation methodology can complicate the testing process and deviate from the ideal situation [170] making the *in vivo* measurements more difficult than *in vitro* ones [182]. Also, *in vitro* studies offer standardized and optimized conditions in the experimental performance which may not be possible to achieve *in vivo* [50, 118].

Influence of sample size:

The adequacy of data is important issue for the success of any research. Sample size and the number of measurement per specimen and statistical test performed can consequently influence the strength of statistical analysis and thus conclusions made can be less relevant or invalid [45]. In addition, the larger the number of measurements per specimen, the greater the precision of the analysis will be [63]. It has been reported that individual measurements at different locations of the margin may reveal significant deviations from the mean, and may render the crowns clinically unacceptable even if the majority of the margin has an excellent fit [66].

Many studies which used small sample size reported large standard deviations compared to the mean value [15, 66, 71, 127] while using a larger sample size produced more consistent data with smaller standard deviation [45, 55, 107]. According to Groten et al [106], when investigating the marginal fit of fixed dental restoration, the smaller sample size can be compensated by larger number of measurement per sample. This conclusion can be demonstrated through Gonzalo et al’s [27] and Lee et al’s [28] studies which used a smaller sample size (n=10) and compensated it with a large number of measurements per sample (60 and 50 measurements respectively) and achieved more consistent distribution of data with small standard deviations compared to the mean values.

Groten et al. [106] used an empirical approach to sample size problem. They used a master steel die to fabricate ten all-ceramic crowns. Marginal gaps were then measured using scanning electronic microscopy before and after cementation starting with 230 measurements per crown. This number was reduced to smaller subsets following systematic and random approaches to verify their impact on the quality of the results. They reported that smaller data sizes led to accelerated rise in the standard of errors and divergent variability of the mean. Accordingly, 50 measurements per specimen were recommended to attain clinically significant information about marginal gap size regardless of the systematic or random approaches of the measurement sites, and at least 20 to 25 measurements per crown could be accepted depending on the required level of precision. Furthermore, a study that utilized a more sophisticated methodology of running 360 gap measurements at 360° concluded that the minimum number of measurements required is 18 for *in vitro* evaluations and 90 for crowns constructed from impressions made intra-orally [63]. Therefore, 4-12 measurements per crown as used by several studies [8, 15, 26, 29, 33, 44, 48, 76] might be misleading.

Influence of finish line:

The effect of different finish line designs (i.e. shoulder, chamfer, feather edge, bevel) on the fit of crowns and FPDs has been widely investigated [13, 15, 25, 51, 115, 152, 155]. However, the conclusions of these studies seem to be contradictory. The possible influence of finish line configuration on the fitting of the crown according to Gavelis et al. [152] occurs during cementation. When the axial wall of the prepared tooth matches the axial wall of the internal crown surface, the escape pathway for cement diminishes, increasing the hydrostatic pressure within the crown until it equals the patient's biting pressure and prevent further seating of the crown [152]. If the cement has not completely set, it continues to escape until the particles at the axial walls prevent further seating [152]. Certain finish lines like shoulder seem to facilitate the escape of cement earlier in the cementation process, and thus improve crown fitting [152].

Influence of cementing:

Measuring the marginal gap of cemented or uncemented crowns can also influence the results of the measurement [22, 23, 31, 76, 148]. It is known that marginal discrepancy generally increases after cementation [25, 138] and that the cementation medium may discontinue the complete seating of full crown resulting in an insufficiently sealed margin of the restoration [152, 161]. Many investigators reported a significantly higher marginal gap after cementation than that before cementation [22, 23, 31, 76, 108]. Furthermore, the cementation techniques such as uncontrolled finger pressure or overfilling of the crown with cement can cause uneven flow of cement with one axial wall having a thick film and the opposite wall having a thin film [136]. Moreover, the type of cement was reported to influence the fit of dental crowns [54, 109, 187].

Influence of veneering:

Veneering process and its associated heat-treatment are known to affect the marginal fit of metal or ceramic core materials [20, 47, 50, 75, 107, 166]. A greater value of marginal discrepancy has been reported to occur during the first firing stage [75, 107], with a greater effect of veneering process occurs in the horizontal plane [110]. Such distortion may clinically result in occlusal displacement of the prostheses and reduction of the load-bearing capacity of all-ceramic restorations [6]. In porcelain fused to metal restorations, design of the finish line affects the amount of marginal distortion occurs during firing [115]. According to Shillingburg et al. [115], the metal bulk in the shoulder design is greater and more rigid, and thus it shows less distortion than that of the chamfer. Difference in the bulk of metal between shoulder and chamfer, however, is probably too small to cause significantly different marginal distortion between the two designs [166]. Another explanation is the thermal incompatibility between metal and veneering porcelain. DeHoff et al. [197] reported, however, that the calculated marginal distortion values resulting from incompatibility of Ni-Cr and Au-Pd alloys and three porcelain products were less than 21 µm in all cases. This finding supports their hypothesis that the resultant metal distortion is not due to system incompatibility, and that poor creep resistance below the glass transition temperature of porcelain could be the major contributing factor [197]. Later, Anusavice et al. [58] demonstrated that incompatibility stress induced by a positive contraction mismatch was not the main cause of marginal distortion of PFM crowns, and suggested that external grinding and internal abrasive blasting of crowns are more likely causes of this effect.

In all-ceramic restorations, firing of the body porcelain occurs at temperatures several hundreds degrees above the glass transition temperature up to the sintering temperature of the veneering material [166]. Once achieved, temperature then drops off at a very high rate of 600 °C/min which results in considerable stresses that can lead to distortion of the restoration [166]. Nevertheless, Kohorst et al. [20] showed by a simplified comparison between thermal expansion behaviors of the framework and veneering material of zirconia based FPDs, that thermal incompatibility is not sufficient to explain the resultant distortion.

Current work investigated the marginal adaptation of all commonly used ceramic systems nowadays whether conventional or CAD/CAM and highlighted all methods and experimental parameters that influence accuracy of marginal gap measurements of these systems through critically appraising the published work under structured criteria. However, it lacked reviewing current off-line published works on this topic, and reviewing published articles in 2012 (till this date) which could be considered as limitations of this review. Yet, 183 articles were reviewed in this study and in-depth analysis was provided.

Conclusions

Within the limitations of this review, it can be concluded that there is a substantial lack of consensus relating to methods used to investigate marginal adaptation of crowns and fixed partial dentures. Considerable differences in testing techniques included experimental set-ups employed and ceramic systems investigated. Regardless, direct view technique is the most commonly used method and recorded the most reproducible results among different studies. Also, conducting an experimental set-up of testing minimum of 30 specimens of the same ceramic system at 50 measurements per specimen should produce reliable and accurate results. Additionally, using a combination of two measurement methods can be useful to verify and validate results.

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Table 1: Analysis of marginal adaptation reported by various methods for different all-ceramic systems

Methods	Number of papers (%)	Range of marginal gap (μm) by ceramic system								References
		1	2	3	4	5	6	7	8	
Direct view technique	**87** (47.5 %)	**7.5-161**	**37-46**	**17-143**	**8.67-61.1**	**63.4**	**46.3-83**	**-**	**13.1-66.4**	[8, 13, 16, 17, 26-30, 33, 36, 40-115]
Cross-sectioning technique	**43** (23.5 %)	**8.3**	**50**	**25-135**	**9-51**	**-**	**15**	**53-56.6**	**18.4-120**	[15, 18, 19, 37, 38, 116-153]
Replica technique	**37** (20.2 %)	**13.4-123**	**68 -130**	**29-117**	**89**	**32.7-206.3**	**48.6-91**	**64-182.7**	**80-189.3**	[10, 12, 20-23, 31, 32, 35, 154-181]
Profile projector	**7** (3.8 %)	**50-117**	**68-110**	**25-44**	**-**	**-**	**-**	**-**	**-**	[24, 25, 182-186]
Digimatic micrometer	**2** (1.2 %)	**Investigated other crown systems (i.e full metal)**								[187, 188]
Micro CT	**3** (1.6 %)	**22**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	[14, 189, 190]
Combination of two methods	**4** (2.2%)	**8.3-28.6**	**-**	**31.9-33.6**	**-**	**-**	**-**	**77-94**	**-**	[191-194]
Total	**183 (100%)**									

(1) In-Ceram Alumina, **(2)** IPS Empress 2 layering technique**,** **(3)** Procera Alumina
(4) Procera Zirconia**,** **(5)** Everest**,** **(6)** Lava, **(7)** Cerec, **(8)** Cercom

Table 2: Marginal gap ranges (μm) of different all-ceramic systems

Ceramic system		Mean Marginal gap (μm)	References
Traditional systems (i.e. follows conventional construction methods like casting or slipping techniques)	In-Ceram Alumina	7.50-161	[13, 33]
	IPS Empress 2 staining technique	97 -130	[23, 161]
	IPS Empress 2 layering technique	36.6-110	[25, 71]
	In-Ceram Zirconia Slip casting	25- 113	[30, 38]
	Procera (Alumina)	17-143	[15, 30]
CAD/CAM systems	Cerec	53-182.7	[12, 38]
	Lava	15-91	[32, 37]
	Everest	32.7-206.3	[12, 31]
	Procera (Zirconia)	8.67-89	[35, 36]