Review Article

A comparison of the marginal and internal fit of CAD/CAM fabricated metal alloy fixed partial dentures

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Background

Fitting accuracy of dental prostheses is essential for clinical success. An ideal marginal and internal fit will minimize plaque accumulation, gingival irritation, cement dissolution and micro leakage as well as enhancing the mechanical behaviour of a fixed partial denture (FPD) (1). Unfortunately, there is disagreement about acceptable marginal and internal fit discrepancies of FPD's (2) from 75-200μm. The range of discrepancies stated (75-200μm) does not jeopardize the clinical performance of the restoration. However, McLean and von Fraunhofer (3) reported that marginal gaps of less than 120μm are clinically acceptable while gaps of less than 80μm are difficult to detect clinically.

The conventional method of fabrication of FPD's is the lost wax method. The method involves making a suitable cast of the patient's mouth, creating a wax template of the FPD framework on the cast, creating a mould of the wax template and casting metal alloy into the mould after the wax has been eliminated. This technique has been a popular approach for FPD framework fabrication for decades (1). The fact however that it involves several technique sensitive steps and a variety of materials makes the control of the restoration fitting accuracy problematic.

Recent advances in manufacturing technology have introduced Computer Aided Design/ Computer Assisted Manufacturing (CAD/CAM) methods for the fabrication of FPD's. Several conventional steps of fabrication are eliminated using these methods. The CAD/CAM approach has three main processes in fabricating an FPD; the digitising process, the designing process and the manufacturing process. Although each process is important, emphasis has been placed on the manufacturing stage as fit of product is dependent on the ability of the system to create the desired prosthesis.

There are two main manufacturing routes of CAD/CAM FPD's: the subtractive and the additive route. The subtractive route is a top-down approach which involves milling the desired article out of a block of the material of choice using a series of burs. This route is currently the most common CAD/CAM technique for the fabrication of metal alloy FPD's. The additive route is a bottom-up approach where the desired article is fabricated layer by layer out of the material of choice. Examples include selective laser sintering and selective laser melting for metal alloy FPD's.

The potential of CAD/CAM fabricated prostheses in respect to fit accuracy is gaining interest. Much has been documented about the importance of the accuracy of fit for a successful CAD/CAM fabricated FPD (5-9). While the literature on the fit of CAD/CAM generated FPD's is quite extensive, the technology is seen to be advancing quickly thus creating a need for regular updating of information (10).

To our knowledge few CAD/CAM studies have been done in relation to dental alloys (2, 11-17). Alloys in dentistry are considered an important

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material to date and is increasingly gaining popularity (18). High strength ceramics are mostly recommended for normal interocclusal clearance cases. While metal or resins are alternative restoration options, metal ceramic is considered the best option where a combination of strength and aesthetics is necessary (19-21). While a systematic review of the fit of zirconia FPDs has been published before (8), no review has been published to date on the fit of CAD/CAM fabricated metal alloys in fixed partial dentures (FPDs).

Problem statements

1. Based on the apparent lack of relevant studies to date, it appears that a systematic review on the fit of CAD/CAM fabricated metal alloy FPD's would be useful.
2. Comparisons between both subtractive and additive methods of CAD/CAM have not been properly investigated.
3. A direct comparison with CAD/CAM methods and the lost wax technique would be benficial for readers.

Objectives

The aim of this study is to systematically review the fit of CAD/CAM fabricated metal alloy crowns and bridges.

Methodology

Search strategy

A summary of the search strategy is presented in Figure 1. The search for literature was primarily based on an electronic search through MEDLINE via the PubMed database. Using Boolean operators, the following keywords were combined: 'fit', 'marginal', 'internal', 'computer aided design', 'computer assisted manufacturing', 'CAD/CAM', 'CAD CAM', 'coping',' crown', 'fixed partial denture', 'fixed dental prosthesis', 'framework', 'alloy', 'metal', 'titanium' and 'cobalt chrome'. Similarly, keywords were used for an electronic search in the Scopus database, Academic Search Complete database, Science Direct database and Web of Knowledge database. No restrictions were performed regarding the publication date up to August 2016. All abstracts were read and inclusion criteria (Table1) were used to eliminate papers irrelevant to this systematic review. Selected papers were analysed and the main findings are presented here. Manual search of references in each paper was performed to find potential papers which fulfil the selected criteria.

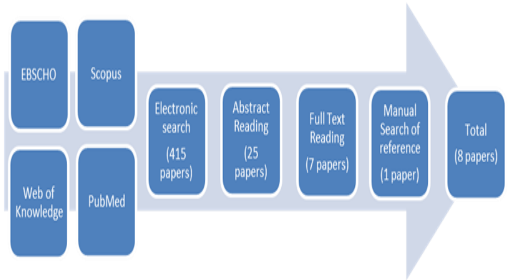


Figure 1: Search strategy of papers selected

Criteria

Inclusion criteria are presented in Table 1. One paper was eliminated as it was not presented in English (22). Papers included concerned metal alloy FPD's constructed by the CAD/CAM method. Both *in vitro* and *in vivo* studies were investigated. Only papers that evaluated and measured fit were used. The definition of fit is illustrated in Figure 2. A vertical marginal fit is defined as the distance between the restoration and the preparation when measured parallel to the long axis of the tooth (23). A horizontal marginal fit is defined as the distance between the restoration and the preparation when measured perpendicular to the long axis of the tooth (23). For this study the axial wall internal fit is defined as the perpendicular distance from the axial wall of the tooth to the restoration and occlusal fit is the perpendicular distance from occlusal wall of the tooth to the restoration. For papers not specifying on the site of internal fit, mean internal fit is displayed.

Study description

A total of 415 papers were initially found using the electronic search. Twenty five papers were then selected after reading the abstracts and applying the inclusion criteria. Seven papers were finally selected after studying the 25 papers and applying the inclusion criteria. Manual search of the references within the selected

Selected Criteria	
Publication type	Published/Peer reviewed
Language	English
Necessary content	FPD must be fabricated by CAD/CAM Fit assessment
Type of study	*In vivo/In vitro* studies
Type of FPD	Single coping/Bridge framework
Material	Metal alloys

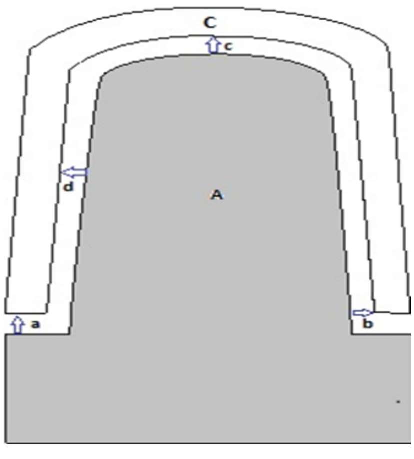
Table 1: Inclusion criteria for the Review

papers identified one more paper in agreement with the inclusion criteria. A total of eight papers were therefore used for the systematic review (Figure 1).

Results

A summary of the selected studies is presented in Table 3. Six selected papers (11-16) were *in vitro* studies and two had both *in vitro* and *in vivo* results (2, 17); five assessed only marginal fit of alloys (2, 11, 13, 16, 17), two assessed internal fit (12, 14) and Han *et al.* 2011 assessed both internal and marginal fit of metallic frameworks to their abutment (15). Witkowski *et al.* 2006 assessed the horizontal marginal fit of alloy coping (16) while six others assessed the vertical fit (2, 11, 13, 15-17). Two studies showed the total internal fit (12, 14) and Han *et al.* 2011 showed the occlusal and axial internal fit (15).

The majority of alloy frameworks were fabricated using milling machines (subtractive route). Three studies had results for fabrication by laser sintering (12, 14, 17) (additive route). The results include fit assessment carried out on parts fabricated by the following CAM systems (Table 2):



A: Tooth abutment; C: Coping; a: Vertical marginal fit; b: Horizontal marginal fit; c: Occlusal internal fit; d: Axial internal fit

Figure 2: Illustration of marginal and internal fit

System	Manufacturer	Origin
PM100 Dental System	PHENIX Systems	France
DC-Titan	DCS Dental	Switzerland
Everest	Kavo Dental GMbH	Germany
Modified I-Mes Premium 4820	I-Mes Wieland	Germany
Procera	Nobel Biocare AB	Sweden
3.3.2.3	KaVo	USA
Pro 50 CAM	Cynovad	Canada
Precimill	DCS Dental AG	Switzerland
BEGO Medifacturing-system	BEGO Medical	Germany

Table 2: CAM systems in selected studies

Discussion

Methods for measuring fit varied in these studies. At present, there are no fit assessment standards (ISO or others). In summary, the methodologies utilised were:

1. Cementation of the dental prosthesis on a master cast with silicone/dental cements followed by sectioning and subsequent measurement with stereomicroscope.
2. Stabilization (pin/loading jig) of dental prosthesis on master cast followed by digital photography of marginal adaptation and analysis with measurement software.

The results of fit of CAD/CAM fabricated alloy FPD's and the conventional method of lost-wax method of all selected studies are displayed in Table 3. Two studies favoured the CAD/CAM over the lost-wax method of fabrication (11, 16) while 3 showed the opposite (12, 13, 15). Ortorp *et al.* 2011 favoured the fit of laser sintered over milled prostheses (12) and Quante *et al.* 2008 favoured fabrication of dental prostheses in gold over cobalt chrome (17). Results were classified to factors that influenced fit of alloys by CAD/CAM:

1. Fabrication system
2. Alloy type
3. Examination methods

Two studies (2, 17) did not show results of fit of prosthesis via the traditional lost wax method but only displayed results of CAD/CAM fabrication. All studies demonstrated the use of CAD/CAM or at least Computer Assisted Manufacturing (CAM) in metal alloy prostheses fabrication. Papers selected used controls that utilize the same material to what was used for the intervention. Materials include cobalt chrome and titanium. Sample sizes of papers selected ranged from 5-20. Ucar *et al.* (2009) was the only paper that did not specify the prostheses type utilised in their study.

There seems to be consensus among authors that CAD/CAM technology is a promising field. However variations between values obtained from different studies, make it impossible to rank CAD/CAM and the conventional lost-wax method. More research could be done to address this matter. The search of papers revealed many studies showing fabrication of dental prosthesis with CAD/CAM, however only few used metal alloys for fabrication. This review only looked at FPD excluding implants; this led to elimination for other type of frameworks related to dentistry. Implant supported FPD related papers were also excluded.

Sample size used in selected studies ranged from 5-20 specimens. Two studies (2, 15) made repeated measurements at specific points on specimens. This however may influence results. The Ortorp *et al.* (2011) paper had high standard deviations, results suggesting an increase in sample sizes would have been beneficial.

Table 3 Summary of selected studies

Referance		Methodology					Results					
		Examination method	System				Sample size	Marginal Fit µm(S.D)		Internal Fit µm(S.D)		
No.	Author and Date		Manufacturer	Prostheses type	Fabrication type	Alloy type		Vertical	Horizontal	Axial	Occlusal	Mean
1	Ucar et al. 2009	Optical microscope-SZ40; Olypus, Tokyo, Japan) then analysed with ImageJ and NIH Image software; National Institute of Helath, Bethesda, Md	PM100 Dental System; PHENIX Systems, France	Crown (not specified)	Lost Wax	Cobalt Chrome	12					50.6(25.1)
					Laser-sintered		12					62.6(21.6)
2	Romeo et al. 2009	Stereo microscope; Wild M5A, Heerbrugg, Switzerland-50X then analysed with Image J 1.32, US National Institues of Health, Bethesda, MA, USA	DC-Titan; DCS Dental, Switzerland	Crown coping	Milled	Titanium	5	20.3(6.7)				
							5	12.6(4.6)				
3	Han et al. 2011	Measuring microscope; Mituyo America Corp, Aurora, III-30X and SEM, JSM-7500F; JEOL, Tokyo, Japan-50X	Everest, Kavo Dental GmbH, Germany	Crown coping	Lost Wax	Titanium	20	52.2(14.2)		67.5(20)	109.8(32.9)	
					Milled		20	59.8(14.9)		51(10.8)	124.6(28)	
4	Shokry et al. 2010	Stereo microscope;Axioskop; Carl Zeiss Microimaging, Inc, Gottinen, Germany then analysez with ImageJ, v,1.37, NIH, Bethesda, Md.	Everest; Kavo Dental GMbH, Biberach, Germany	Crown coping	Lost Wax	Titanium	5	81.5(10.7)				
					Milled		5	24.1(1.9)				
5	Ortorp et al. 2011	Stereo microscope; Wild M7A, Wild Heerbrugg LTD, Heerbrugg, Switzerland then analysed with Leica Application Suite v. 3.3.1, Leica Microsystem GmbH		Bridge framework	Lost Wax	Cobalt Chrome	8					133(89)
			Modified I-Mes Premium 4820, I-Mes Wieland, Germany		Milled		8					166(135)
			Procera; Biomain AB, Helsinborg, Sweden		Laser-sintered		8					84(60)
6	Tan et al. 2007	Canon 10D 100-mm macro lens, Canon USA, Inc., Lake Success, NY then analysed with Image Pro Plus version 2.0, Media Cybernetics, Silver Spring, MD	3.3.2.3, KaVo, USA	Crown coping	Lost Wax	Titanium	10	23.9(9.8)				
					Milled		10	79.4(25.5)				
7	Witkowski et al. 2006	Stereomicroscope (Axioskop; Zeiss. Oberkochen, Germany then analysed with analySIS 2.1; soft imaging software GmbH, Munster, Germany		Crown coping	Lost Wax	Titanium	16	43.6(25.6)	18.7(13.6)			
			Pro 50 CAM, Cynovad		Milled		16	23.9(6.7)	36.7(20.9)			
			Precimill; DCS Dental AG				16	7.8(6)	10.1(5.5)			
			Everest; KaVo Dental GmbH				16	38.4(18.2)	38.8(12)			
8	Quante et al. 2007	Light microscope; M420, Wild, Netherlands then analysed with Leica Manager; Leica, UK	BEGO Medifacturing-system, BEGO medical, Germany	Crown coping	Laser-melting	Cobalt Chrome	14	93				
			BEGO Medifacturing-system, BEGO medical, Germany		Laser-melting	Gold Platinum	14	73				

Fabrication system

Ucar *et al.* (2009) stated that the laser sintering process provides promising fit results, comparable to the lost wax method. The study laser sintered a CoCr and had two controls of conventional fabrication of CoCr and NiCr. No significant difference was found between methods. The use of finger pressure for coping cementation prior to fit evaluation is however of concern as it may have introduced a systematic error in the internal fit measurement.

Ortorp *et al.* 2011 found laser sintering produced significantly ($p<0.05$) better vertical and marginal fit when compared to milling (12). In their study different techniques were compared in vitro: conventional casting, milled wax and casting, milled CoCr and laser sintered CoCr. There was no significant difference found when laser sintering was compared to the lost-wax technique. However when milling was compared to the lost-wax technique, results favoured the conventional ($p< 0.05$). The paper compared bridge framework designs on premolars and molars as abutments. Considering the design had two coping abutments that have the same points to be analysed. The conclusion; mean of internal and marginal fit between the two different abutments would not have been possible.

The conventional method for fabrication of dental prostheses is the lost-wax method. Reports (Table 3) suggest that this method is able to fabricate alloy FPD's well within accepted clinical fit (17). For this review, the lost-wax method is considered the benchmark for methods of fabrication. However, van Noort (2012) states that the future of dentistry lies with CAD/CAM technology (10). With advantages of quick fabrication, reliable results and ability to create complex designs (10) makes us wonder if the lost wax technique could be replaced. Nevertheless, until concrete evidence is displayed; the lost-wax method still remains integral part of dental prostheses fabrication.

Contradictory results have been identified as some studies favour conventional versus CAD/CAM techniques (12, 13, 15) and vice versa (11, 16) in respect to fit. However, all papers agree that milling with CAD/CAM is promising as marginal discrepancies were all within an acceptable range. Tan *et al.* 2007 may have incorporated a biased methodology that can influence results. Author had manually applied 4 layers of die spacer for the conventional method but did not state the thickness of the die spacer. 80µm of die spacer was applied for the CAD/CAM group. Differences in die spacer thickness may have had an influence in results.

Variability in tools involved makes it difficult to rank the systems in terms of accuracy of fit. Most manufacturers use the subtractive routes but variation in different tools used for the milling procedure again disallows the use of a proper meta-analysis. The diameter of cutting burs used for milling varies from a 0.8-1.0mm (16). To our knowledge, there is no such evidence stating that size of burs has an effect on fit. However it may be a potential limitation.

Limitations also occur as scanner systems and software for designing used in the selected papers differ. The variation it poses, although less important as this review only presents the outcome of the FPD's could have influence on results. Future research to minimize variability's is there for suggestion.

Alloy type

Quante *et al.* (2008) found that the type of alloy used to fabricate CAD/CAM prostheses does not affectthe marginal fit. Within the investigated studies, three alloys were used with different systems namely titanium, cobalt chrome and gold platinum. Titanium appears to have better fit (Table 3), however due to inter-measurement variability, this outcome would need to be investigated further.

Examination methods

Marginal and internal fit evaluation required cementing of prosthesis on to master cast. Various dental cements were used to stabilize the prosthesis and measurement of thickness of cement would provide fit. Sectioning however meant that copings would have to be destroyed. The silicon replica technique could be an alternative to the methods. This technique involved applying low viscosity silicone on internal surfaces of coping and applying load on to cast. After setting of silicone, high viscosity silicone is applied over the set putty for stabilisation and measurement of low viscosity putty gives the fit of restoration. Validation of non-destructive technique has been done and results were comparable to the use of zinc phosphate cement (24).

Four papers (2, 11, 13, 16) used external microscopic examination with the utilisation of cameras and measuring software. However, this method has its limitation in being able to measure fit of marginal opening only if sectioning was not performed. If it was done, a method to stabilize prostheses in cast would have to be applied.

There are no standard methods of evaluation of fit yet to date. Consequently, a variability in measurement systems is noticed and could well affect results. Most ISO standards directed towards dentistry is looking at health and safety issues (25). There is none to be found on measurement and accuracy of CAD/CAM systems. Currently, development in ISO standards of the system is still in progress. Until a standard methodology is created, variations of results will continue to be displayed in research.

Conclusion

Within the limitations of this review, the following conclusions may be drawn with regard to the use of CAD/CAM techniques in the fabrication of FPDs:

1. Results for marginal fit of metal alloy FPD's ranging from 7.8-93µm and internal fit ranging from 50.6-166µm suggest that CAD/CAM methodology may be appropriate to generating a clinically acceptable fit in metal alloy FPD's.
2. Variations exist in the method of determining accuracy of fit indicating the need for an ISO standard as this will allow a proper meta-analysis to be carried out.
3. Variations in study don't allow a conclusion to favour CAD/CAM over the conventional method. The conventional lost-wax techniques remain an appropriate method of fabricating dental prostheses.

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