DENTAL MATERIALS 27 (2011) 356–363

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.intl.elsevierhealth.com/journals/dema

The fit of cobalt–chromium three-unit fixed dental prostheses fabricated with four different techniques: A comparative in vitro study

Anders Örtorp[a,*], *David Jönsson*[b], *Alaa Mouhsen*[b], *Per Vult von Steyern*[b]

[a] *Department Prosthetic Dentistry/Dental Materials Science, Institute of Odontology, The Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden*

[b] *Department of Dental Technology, Faculty of Odontology, Malmö University, Malmö, Sweden*

ARTICLE INFO

Article history:
Received 7 March 2010
Received in revised form
1 September 2010
Accepted 23 November 2010

Keywords:
Accuracy
Cement film thickness
Marginal gaps
Discrepancies
Fabrication techniques

ABSTRACT

Objectives. This study sought to evaluate and compare the marginal and internal fit in vitro of three-unit FDPs in Co–Cr made using four fabrication techniques, and to conclude in which area the largest misfit is present.

Methods. An epoxy resin master model was produced. The impression was first made with silicone, and master and working models were then produced. A total of 32 three-unit Co–Cr FDPs were fabricated with four different production techniques: conventional lost-wax method (LW), milled wax with lost-wax method (MW), milled Co–Cr (MC), and direct laser metal sintering (DLMS). Each of the four groups consisted of eight FDPs (test groups). The FDPs were cemented on their cast and standardised-sectioned. The cement film thickness of the marginal and internal gaps was measured in a stereomicroscope, digital photos were taken at 12× magnification and then analyzed using measurement software. Statistical analyses were performed with one-way ANOVA and Tukey's test.

Results. Best fit based on the means (SDs) in μm for all measurement points was in the DLMS group 84 (60) followed by MW 117 (89), LW 133 (89) and MC 166 (135). Significant differences were present between MC and DLMS ($p < 0.05$). The regression analyses presented differences within the parameters: production technique, tooth size, position and measurement point ($p < 0.05$).

Significance. Best fit was found in the DLMS group followed by MW, LW and MC. In all four groups, best fit in both abutments was along the axial walls and in the deepest part of the chamfer preparation. The greatest misfit was present occlusally in all specimens.

1. Introduction

To achieve a clinically acceptable result for fixed dental prostheses (FDPs) the fit of the construction is one important requisite [1,2] for a good long-term prognosis [1–7]. A study performed by Foster [7] on 142 failed FDPs concluded that one important reason for this technical complication was an unacceptable fit. An unacceptable marginal gap could result in cement washout [2,8,9] with subsequent biological compli-

* *Corresponding author at*: Department Prosthetic Dentistry/Dental Materials Science, Institute of Odontology, Box 450, SE-405 30 Gothenburg, Sweden. Tel.: +46 31 786 3202; fax: +46 31 786 3193.
E-mail address: anders.ortorp@vgregion.se (A. Örtorp).
0109-5641/$ – see front matter
doi:10.1016/j.dental.2010.11.015

cations such as secondary caries, periodontal problems and pulpitis [1,10,11].

The definition of the terminology fit varies between different studies. Further, different techniques for measuring the marginal and internal gaps are available [1,3,4,6,9,12–14]. However, current techniques for these measurements are not optimal, as discussed by others [3,6], and reports in this field have not been entirely consistent [1,3,4,13,15,16]. Even though results are somewhat inconsistent, both older and more recent studies have consistently shown that fabricated fixed prosthodontics have failed to produce an optimal fitting crown or FDP [1,9]. However, with the increasing number of computer-aided design/computer-aided manufacturing (CAD/CAM) techniques in restorative dentistry [1,13,17–20], digitalised information and digitised techniques could also be a valuable resource for the future development of dentistry in the area of fit.

Today, there is no consensus regarding cement film thickness and clinical acceptance. However, long-term follow-up and laboratory studies discuss different levels of gaps for clinical acceptance [21]. McLean and von Fraunhofer [22] concluded that for single tooth restorations to be clinically acceptable, the maximum gap should be 120 μm. Studies also show that the longer the FDPs are, the larger is the risk of distortion [23,24]. In addition, the heavier a metal construction, the more distortion is present [25]. The latter is probably not a risk for cobalt–chromium (Co–Cr) constructions because of their low weight.

The few published studies on the fit of constructions fabricated in Co–Cr have demonstrated marginal discrepancies of 74–99 μm, with internal gaps ranging from 250 to 350 μm using laser melting technology on single crowns [1], and with laser-sintered Co–Cr crowns with a mean internal gap of 63 μm [16]. Furthermore, in a recent study on cement-retained implant supported cast Co–Cr frameworks, the mean vertical misfit was 78 μm [14]. Dental interest in Co–Cr has increased due to its low price and different fabrication methods [1,16]. However, there are few published studies on properties such as biocompatibility, long term effects and the area of fit on FDPs for this material and the new fabrication methods [26,27]. Several techniques for making a Co–Cr construction for fixed prosthodontics are available today, and after the conventional lost-wax technique [1,24] CAD/CAM was introduced. Two fabrication methods are primarily used with this new digitised technique, either by milling [28] the frameworks from a block of Co–Cr or by using direct laser metal sintering (DLMS) [1,16,26]. Unlike the milling technique, DLMS sinters a metal powder in layers, which is then fused together by laser welding [1,26,27]. The advantages of CAD/CAM techniques are simplicity, reduced costs and manufacturing time [27,29].

The aims of this in vitro study were to evaluate and compare the marginal and internal fit between three-unit FDPs in Co–Cr made using four fabrication techniques, and to conclude in which area the largest distortion on the FDPs are present. The null hypothesis was that there would be no differences in fit between the tested groups.

2. Materials and methods

2.1. *Fabrication of models*

One master model with two posterior abutment teeth, and 360° chamfer preparations with 16° total occlusal convergence (TOC), was made in epoxy resin (EpoFix Resin & EpoFix Hardner, Struers A/S, Ballerup, Denmark). To standardise impression-making, a device was constructed in type IV stone, and tracks were milled in the device for positioning of the trays. Eight silicon impressions (Colténe® President, putty soft/light body, Colténe Whaledent, Altstätten, Switzerland) were performed on the master model with a metal frontal tray. Each impression was wet with Wax Pattern Cleaner (Jelenko Dental Health Products, NY, USA) and poured under vibration; for one master model and one working model for each method. The 32 master models (Fig. 1) were fabricated using a type IV stone (GC Fujirock®, GC Corporation, Leuven, Belgium). Eight of the working models (group Conventional lost-wax method (LW) were poured with the same type IV stone, and the remaining 24 (milled wax with lost-wax method (MW)), milled Co–Cr (MC), direct laser metal sintering (DLMS)) were poured with type IV stone (Everest® Rock, KaVo, Biberach, Germany). All models were standardised-trimmed, and the working mod-

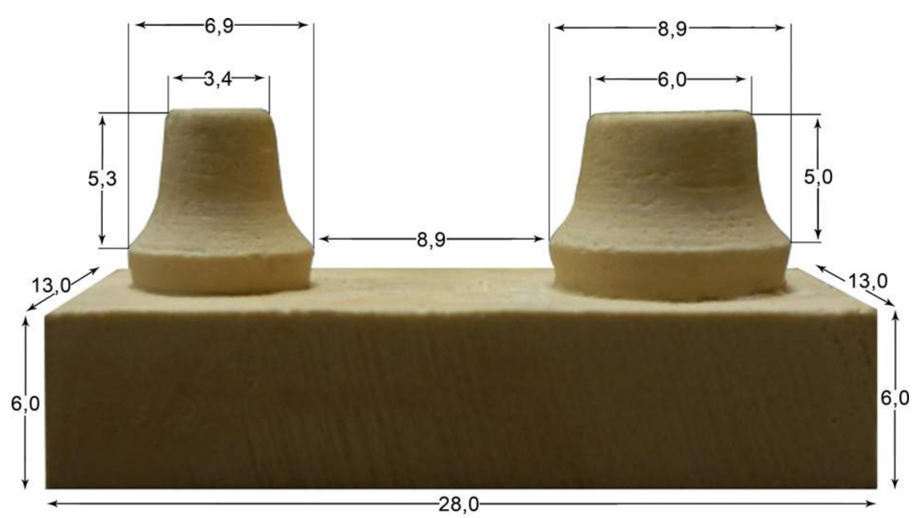

Fig. 1 – Dimensions in mm of the master model in plaster.

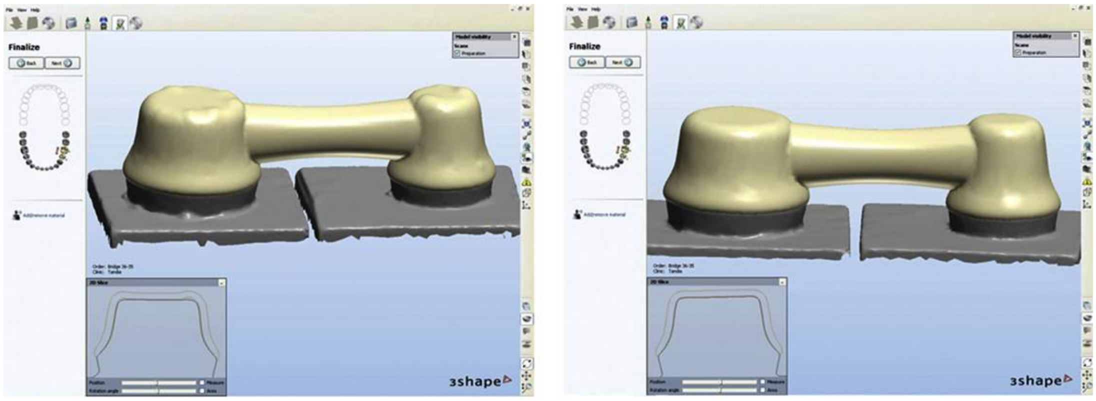

Fig. 2 – Screen shot on CAD frameworks. CAD for milled framework (MC). Note the occlusal differences due to "drill compensation" (left), CAD for sintering (DLMS) (right).

els to be scanned were sectioned, prepared with pins (Dowel Pin & Kunst, Edenta GmbH, AU/SG, Switzerland) and based with type III stone (Class III, BK Giulini GmbH, Ludwigshafen, Germany). The working models for the LW group were coated with one layer of Die Hardener (Stumpflack Klar, S&S Scheftner GmbH, Mainz, Germany) and five layers of Die Spacer (Stumpflack Die Spacer blau, 10 μm, S&S Scheftner GmbH). Each layer was approximately 10 μm with a total thickness of 50 μm [17]. The dies were applied with spacer within 0.5 mm of their cervical margins.

2.2. *Fabrication of frameworks*

In total, 32 three-unit Co–Cr FDPs were fabricated with four different production techniques, with eight specimens in each group. The frameworks were dimensioned with a thickness of 0.5 mm, with a mean connector area of 9 mm^2. The outer surfaces of all frameworks were polished with a metal bur (Hartmetall-Fräser, Edenta GmbH), and the frameworks were cleaned using airborne particle abrasion (Basic Quatro IS, Renfert GmbH, Hilzingen, Germany) using 125-μm aluminum oxide with 3 bars of pressure. No other adjustments of the frameworks were performed.

Conventional lost-wax method (LW): To obtain the same outer surface, a silicone impression of a Co–Cr framework from the method study was performed. Wax isolate (Kleen Lube, KerrLab, Orange, USA) was applied to the models. Through an occlusal opening in the silicone form, melted wax (Ultra-Waxer™, KerrLab) was poured, the form was removed and the wax was adjusted by an electric wax knife. Wax patterns were examined by two of the investigators to ensure that there were no visible gaps between the patterns and die margins. The wax patterns were connected with three 3-mm long wax spruces (Deton Ø 3 mm, Yeti Dental GmbH, Engen, Germany) on the abutments and the connector to the base of the sprue former. A ring free technique (Rapid-Ringless-System, Bego, Bremen, Germany) was used, and the wax patterns were invested with a phosphate bonded investment (GC Stellavest®, GC Corporation) according to the manufacturer's instructions. The patterns were casted in Co–Cr-alloy (Wirobond C; Co 61, Cr 26, Mo 6, W 5, Si < 2, Fe < 2, Ce < 2, C < 2, Bego) in an automatic vacuum and pressure casting machine (Nautilus CC, Bego). The castings were sectioned from the spruces by a grind disc (Grind Disc 3000, Forshaga, Sweden).

Milled wax with lost-wax method (MW): The dies were read by a scanner (D-640™, 3Shape A/S, Copenhagen, Denmark). The scanner software program (DentalDesigner 2008-1, 3Shape A/S) transferred the data points into 3D CAD data. In the CAD process, modeling was performed on the digitalised abutments, and parameters in the program were given for milling in wax (LunaCast®, ACF GmbH, Amberg, Germany). The cement film thickness was set to 50 μm with no space 0.5 mm from the margin. Data was sent to a milling center for computerised milling (Modified I-Mes Premium 4820, I-Mes Wieland, Wieland, Germany) from one piece of wax. The casting technique and adjustments were performed similarly to that described above for the LW method. However, because of the wax composition it was burned out for 10 min longer than in the LW method.

Milled Co–Cr (MC): The CAD/CAM technique (Fig. 2) was performed as described above, with adjustments for milling of Co–Cr alloy blocks (Co 64, Cr 21, Mo 6, W 6, Si 1.2, Mn 0.7, Nb 0.5, B 0.25, C 0.2, N 0.15; LunaNEM, ACF GmbH).

Direct laser metal sintering (DLMS): The same CAD technique was used in this method as described above with software adjustments for this technique (Fig. 2). Data was sent for production of the frameworks with the Co–Cr powder (CoCrMoWSi; Co 63, Cr 25, Mo 5, W 6, Si 1) in a laser sintering machine (Biomain AB, Helsingborg, Sweden) with a laser processed density of 8.7 g/cm^3. The thickness of the sintered layers was between 0.02 and 0.04 mm. The manufacturer (Biomain AB, Helsingborg, Sweden) used airborne particle abrasion using 250-μm aluminum oxide with 3 bars of pressure only at the outer surface.

2.3. *Cementing and sectioning of the specimens*

Frameworks were steam cleaned (Elmasteam ES3, Elma GmbH, Singen, Germany), dried, and primed (Monobond-S, Ivoclar Vivadent, Schaan, Liechtenstein) before cementation. A blue color (Dr. Oetker, Bielefeld, Germany) was mixed into the cement before the frameworks were cemented on their respective master model with dual cured resin cement (Variolink® II, Ivoclar Vivadent). The frameworks had a pres-

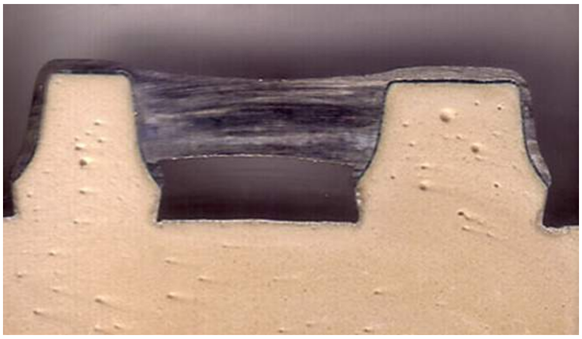

Fig. 3 – Sectioned framework from the direct laser metal sintering (DLMS) group.

sure of 50 N [11,30] during cementation with a loading device. A UV lamp (Bluephase®, Ivoclar Vivadent) was used and excess cement was removed. The cemented frameworks on the master casts were embedded in epoxy resin for 12 h to stabilise the position, and the blocks were glued to a metal plate and screwed onto the saw device. The frameworks were sectioned with a low speed saw (IsoMet®, Buehler LTD, Lake Bluff, USA) centrally in the mesiodistal direction (Fig. 3). The half of the frameworks not left in the saw device was used to analyze the cement film thickness.

2.4. *Analyses and measurements of the specimens*

All measurements were on the cemented frameworks on the master casts. Analysis was performed using a stereo microscope (Wild M7A, Wild Heerbrugg LTD, Heerbrugg, Switzerland) that was calibrated by one experienced engineer according to the manufacturers instructions, before the study started. Furthermore digital photos (FC 420, Leica Microsystems GmbH, Wetzlar, Germany) were taken with a magnification of 12×, and analyzed in a measuring program (Leica Application Suite v. 3.3.1, Leica Microsystems GmbH). For each abutment, 11 reference measurement points were analyzed (Fig. 4) [4,10]. In total, 704 measurements were performed on the 32 frameworks by one blinded observer.

2.5. *Statistical analysis*

Differences between the four fabrication methods were submitted to one-way ANOVA and Tukey's test on a mean of the

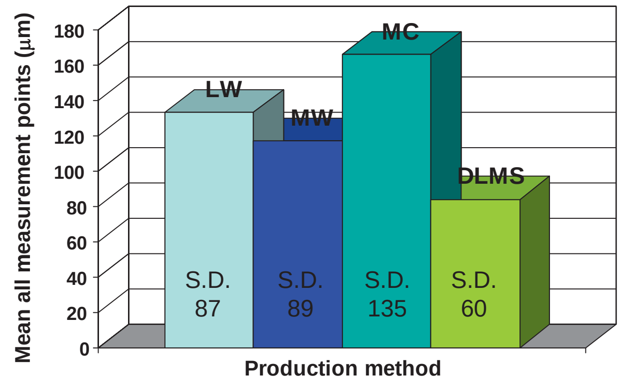

Fig. 5 – Total mean (SD) for all measurement points of cement film thickness for the four production methods ($n = 176$). Conventional lost-wax method (LW), Milled wax with lostwax method (MW), milled Co–Cr (MC), Direct laser metal sintering (DLMS). Statistically significant differences between group MC and DLMS ($p < 0.05$), between the other groups no differences were present ($p > 0.05$).

discrepancy on all frameworks. All tests were performed with a confidence interval of 95%. Furthermore, a regression analysis was performed on fabrication method, tooth, position, adjusted cement film thickness, and measurement point to evaluate differences within these parameters. The level of significance was set at 5%.

3. Results

3.1. *The mean cement film thickness*

The mean and SDs of the cement film thickness for the four production methods are given in Fig. 5. The largest discrepancies were present for the MC group. The mean and SDs for all measurement points are presented in Table 1, where point seven had the largest cement film thickness. Tables 2 and 3 indicate the cement film thickness for different measurement points, tooth size and production method.

3.2. *Regression analysis results*

The regression analysis on all 704 discrepancy values showed statistically significant differences in the results regarding:

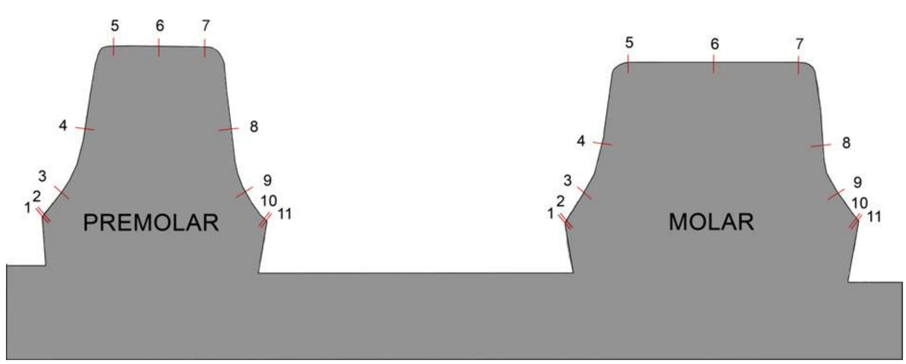

Fig. 4 – Eleven reference points were measured on each abutment.

Table 1 – The total mean (SD) of cement film thickness for the 11 measurement points on the premolar and molar for all four production methods.

Point	1	2	3	4	5	6	7	8	9	10	11
Mean (μm)	142	92	63	80	177	186	203	70	99	105	158
SD	62	52	48	28	80	82	80	30	50	53	79

Methods: Conventional lost-wax method (LW), milled wax with lost-wax method (MW), milled Co–Cr (MC), direct laser metal sintering (DLMS) ($n = 64$ per measurement point).

Table 2 – Mean (SD) in μm of cement film thickness for all measurement points in premolars and molars for all four production methods.

Point	Group			
	LW (mean (SD), μm)	MW (mean (SD), μm)	MC (mean (SD), μm)	DLMS (mean (SD), μm)
Tooth (premolar)				
1	113 (22)	102 (36)	185 (117)	64 (20)
2	95 (25)	55 (42)	160 (108)	26 (26)
3	70 (31)	33 (28)	86 (101)	45 (40)
4	214 (32)	23 (10)	23 (13)	26 (17)
5	164 (49)	170 (71)	277 (110)	78 (44)
6	243 (100)	100 (31)	256 (126)	145 (58)
7	194 (56)	99 (38)	304 (165)	164 (50)
8	287 (63)	34 (21)	23 (11)	26 (16)
9	87(58)	90 (33)	100 (69)	76 (44)
10	31 (27)	89 (40)	154 (79)	30 (39)
11	89 (57)	114 (38)	220 (116)	75 (43)
Total	144 (92)	83 (55)	163 (135)	69 (58)
Tooth (molar)				
1	123 (69)	155 (60)	260 (128)	133 (44)
2	84 (66)	110 (33)	117 (85)	89 (32)
3	48 (57)	84 (38)	54 (75)	85 (35)
4	227 (78)	39 (23)	33 (23)	57 (26)
5	149 (77)	166 (73)	275 (150)	138 (68)
6	114 (65)	194 (95)	259 (127)	169 (56)
7	169 (59)	258 (97)	289 (123)	147 (49)
8	104 (59)	21 (15)	30 (27)	33 (29)
9	27 (18)	181 (72)	137 (71)	97 (34)
10	114 (42)	194 (68)	174 (89)	52 (39)
11	169 (82)	271 (124)	236 (134)	87 (39)
Total	121 (80)	152 (103)	169 (136)	99 (58)

Methods: Conventional lost-wax method (LW), milled wax with lost-wax method (MW), milled Co–Cr (MC), direct laser metal sintering (DLMS).

production method, tooth size, position and measurement point. To simplify the analytical method, LW was kept constant while differences in production methods were seen between LW MC, and DLMS ($p < 0.05$). The MC group had significant higher discrepancy values than the LW group. For the parameter of tooth size between premolar and molar, the molar showed total higher discrepancy values ($p < 0.05$; Table 2). For the parameter position where the mesial placement was constant, differences were present, with higher discrepancies occlusally ($p < 0.05$) and distally ($p < 0.05$). For the parameter of measurement point, between all 704 points where point one was a constant all points were significantly

Table 3 – Mean (SD) in μm of cement film thickness for the three occlusal measurement points 5–7, for four different production methods.

Point	Group							
	LW (mean (SD), μm)		MW (mean (SD), μm)		MC (mean (SD), μm)		DLMS (mean (SD), μm)	
	Premolar[a]	Molar[a]	Premolar[a]	Molar[a]	Premolar[a]	Molar[a]	Premolar[a]	Molar[a]
5, 6, 7	200 (68)	144 (67)	123 (47)	206 (88)	282 (134)	274 (133)	129 (51)	151 (58)

Methods: Conventional lost-wax method (LW), milled wax with lost-wax method (MW), milled Co–Cr (MC), direct laser metal sintering (DLMS) ($n = 96$ per production method and each tooth).

[a] Tooth.

different ($p < 0.05$) except for point 11 ($p > 0.05$). Best fit independent of the different parameters was in point three and the largest discrepancies were present in point seven. No differences were found for the parameter of set cement film thickness with values of 0 μm for points 1, 2, 10, 11 and 50 μm for points 3–9 ($p > 0.05$).

4. Discussion

There are different ways to study and analyze the fit of dental restorations [3,4]. In this study the frameworks were sectioned centrally to analyze the marginal and inner fit of the constructions. Furthermore, to minimise the impact of impression-taking, eight impressions were taken and working models and master cast were produced. No wear of the master models was hereby set. To standardise the scanning technique the same scanner was used for the three techniques, and an automatic casting machine was used for the casting technique for optimal melting. When fabricating a framework, most steps are in the manual LW technique [24]. The use of a spacer to obtain a thickness of 50 μm, manual waxing, removing the wax to adapt it on the cone [24], the thickness of the wax, storing time and operator skill are some risk factors that can lead to distortion [31]. To minimise some of these factors, the same operator performed the waxing and casting, and two persons examined and accepted the waxing. No microscope was used to check the marginal areas to have a similar situation as in normal practice. Further, a thick connector was chosen and the storing time of the wax was minimised, and all manufacturers' instructions were followed [18]. A ring free technique was also used to minimise the distortion [18]. Few manipulations of the frameworks were performed to minimize the critical steps affecting the fit with exception for airborne particle abrasion and outer surface polishing with a bur. However these steps were performed in the same way for all four production techniques. The main limitations of this study are that only vertical gaps were examined and no horizontal planes were measured, as performed by others [2].

There was an obvious shrinking in the LW group that was set close to the connector and the abutment teeth at the fitting surface of the crowns (premolar: point eight, molar: point four), probably due to the waxing technique also seen by Kunii et al. [17], which registered a thicker cement film on the side where the pontic was connected. This phenomenon was also present in the MW group in this study, but not as obviously as for the LW group. The two other groups (MC, DLMS) also tended toward this pattern of distortion. The MW group is a combination of old and new techniques. In comparison with the traditional LW group, it presented the same amount of measurement points with large distortion values. However, the LW group had generally higher values with the exception of the areas of points five and seven where the drill compensation affected the milling process. One explanation for the larger distortion in the LW group could be that the spacer is difficult to standardise [9,15], and distortion could be set when the wax is removed from the model.

The CAD/CAM technique contains fewer production steps compared to the LW technique [31]. However, there are three main factors that could affect the fit: the precision of the scanner that reads the abutments, how the software can transform the scanning data into a 3D model in the computer, and the precision of the machine that will CAM the objects from the CAD data [19]. According to the manufacturer, the scanner has a precision of 20 μm. However, according to Persson et al. [19] a scanner using laser technique tends to make sharp edges rounder. Possible explanations for this could be optical properties of the plaster or the camera used. This study used a special plaster with low reflections. In addition, the finish line in the chamfer preparation was manually marked in the CAD program, which could be one factor affecting the results in points 1 and 11.

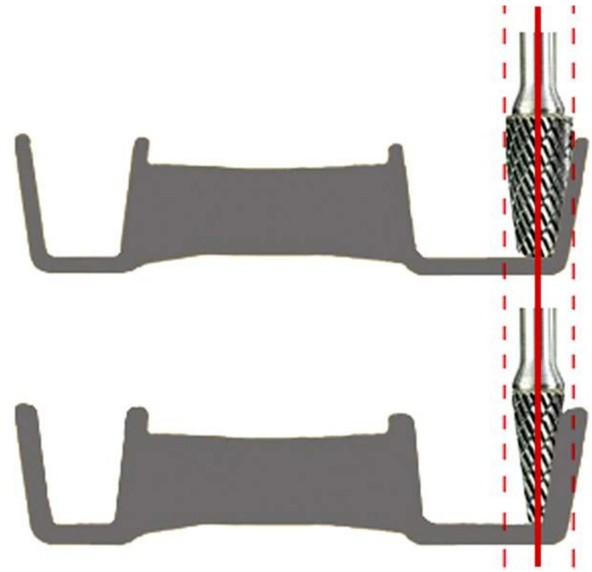

Fig. 6 – A new milling device and correct milling (upper), a worn milling device with a risk of less milling of the Co–Cr on the inner side of the framework if the machining process does not fully compensate for this (lower).

During the CAD process of the frameworks for the two milling groups, the "drill compensation" had to be activated. The preparations were normal with straight transition between the occlusal surface and the axial walls. The smallest milling burs used had a diameter of 1 mm, and to compensate for this a special design was made in the CAD program to obtain access for the milling burs. Hence, the cement film thickness became larger in this area (points five and seven) for the MW and MC groups. The DLMS group, which was also designed in the CAD program, needed no drill compensation (Fig. 2). The MC group had higher distortion values than MW in this area, probably due to problems placing the frameworks in the MC group (too tight fitting). This could be explained by wear of the milling burs when milling such a hard material as Co–Cr (Fig. 6). Therefore, the burs must be changed often to reduce the risk of using burs with decreased diameters, in case the milling machine lacks the capacity to fully compensate for this phenomenon. Vibrations in the milling device could also be a reason for the results in the MC group. Another study [17] has also reported that the cement film thickness is largest occlusally, and one of the reasons for this is the TOC [15]. In this study, the TOC was 16° and probably not the main reason for the occlusal discrepancies in all the 4 groups. An alternative reason could be problems with the cement flow [32].

Laurent et al. [12] showed that in vitro studies present better quality of fit in a controlled laboratory environment with optimal circumstances, than in a clinical setting. However, the production procedures for dental restorations in the dental laboratory do affect the fit more than the study design [30]. The main clinical and laboratory variables are impression making, master cast fabrication, die spacing, fitting procedures and cementation [33]. Accordingly, future CAD/CAM techniques could minimise some of these risk factors proven in the DLMS group were few critical manual steps are present.

Today, there is no consensus of the clinically acceptable cement film thickness in FDPs [16]. Constructions fabricated in Co–Cr have demonstrated internal gaps ranging from 250 to 350 μm using laser melting technology on single crowns [1], and with laser-sintered Co–Cr crowns on central incisors with a mean internal gap of 63 μm [16]. This study presents the lowest values for the DLMS group with a mean value below 100 μm followed by the MW, LW and MC groups. Several studies have discussed the clinically acceptable marginal gap, and 100 μm has been mentioned as one acceptable level [1]. For single tooth restorations 120 μm has also been proposed to be the maximum acceptable value for marginal gap [22]. In this study on FDPs, only the DLMS group present values lower than 133 μm. For this reason, the techniques must be refined. For the CAD/CAM technique, development could probably speed up production by excluding time-consuming steps. These advances and the rapid development of digitised processes will continue, making this computerised technique more cost effective and flexible with better accuracy and precision. Initially a new technique is often costly, which is a potential limitation. More research is needed to develop the digitised technique and improve its competitiveness.

5. Conclusions

Within the limitations of this in vitro study, the following conclusions could be drawn:

Best fit was in the direct laser metal sintering (DLMS) group, followed by milled wax with lost-wax method (MW), conventional lost-wax method (LW) and milled Co–Cr (MC).

Best fit in both abutments in all four groups was along the axial walls and in the deepest part of the chamfer preparation. The largest discrepancies were occlusally in all specimens.

Differences were observed within these parameters: production technique, tooth size, position and measurement point but not in set cement film thickness.

The null hypothesis was that there would be no difference in fit between the tested groups was rejected.

Acknowledgement

The specimens' were supported by Amberger Central Fräse-Center GmbH, Biomain AB and Denthouse AB.

REFERENCES

[1] Quante K, Ludwig K, Kern M. Marginal and internal fit of metal–ceramic crowns fabricated with a new laser melting technology. Dent Mater 2008;24:1311–5.

[2] Vigolo P, Fonzi F. An in vitro evaluation of fit of zirconium-oxide-based ceramic four-unit fixed partial dentures, generated with three different CAD/CAM systems, before and after porcelain firing cycles and after glaze cycles. J Prosthodont 2008;17:621–6.

[3] Jahangiri L, Wahlers C, Hittelman E, Matheson P. Assessment of sensitivity and specificity of clinical evaluation of cast restoration marginal accuracy compared to stereomicroscopy. J Prosthet Dent 2005;93:138–42.

[4] Holmes JR, Bayne SC, Holland GA, Sulik WD. Considerations in measurement of marginal fit. J Prosthet Dent 1989;62:405–8.

[5] Mejia R, Tobon SM. Marginal fit of metal ceramic restorations subjected to a standardized postsoldering technique. J Prosthet Dent 2000;83:535–9.

[6] Limkangwalmongkol P, Chiche GJ, Blatz MB. Precision of fit of two margin designs for metal–ceramic crowns. J Prosthodont 2007;16:233–7.

[7] Foster LV. Failed conventional bridge work from general dental practice: clinical aspects and treatment needs of 142 cases. Br Dent J 1990;168:199–201.

[8] Soriani NC, Leal MB, Paulino SM, Pagnano VO, Bezzon OL. Effect of the use of die spacer on the marginal fit of copings cast in NiCr, NiCrBe and commercially pure titanium. Braz Dent J 2007;18:225–30.

[9] Mitchell CA, Pintado MR, Douglas WH. Nondestructive, in vitro quantification of crown margins. J Prosthet Dent 2001;85:575–84.

[10] Kokubo Y, Ohkubo C, Tsumita M, Miyashita A, Vult von Steyern P, Fukushima S. Clinical marginal and internal gaps of Procera AllCeram crowns. J Oral Rehabil 2005;32:526–30.

[11] Tjan AH, Li T, Logan GI, Baum L. Marginal accuracy of complete crowns made from alternative casting alloys. J Prosthet Dent 1991;66:157–64.

[12] Laurent M, Scheer P, Dejou J, Laborde G. Clinical evaluation of the marginal fit of cast crowns-validation of the silicone replica method. J Oral Rehabil 2008;35:116–22.

[13] Bindl A, Mörmann WH. Marginal and internal fit of all-ceramic CAD/CAM crown-copings on chamfer preparations. J Oral Rehabil 2005;32:441–7.

[14] Oyagüe R, Turrión A, Toledano M, Monticelli F, Osorio R. In vitro vertical misfit evaluation of cast frameworks for cement-retained implant-supported partial prostheses. J Dent 2009;37:52–8.

[15] Milan FM, Consani S, Correr Sobrinho L, Sinhoreti MA, Sousa-Neto MD, Knowles JC. Influence of casting methods on marginal and internal discrepancies of complete cast crowns. Braz Dent J 2004;15:127–32.

[16] Ucar Y, Akova T, Akyil M, Brantley W. Internal fit evaluation of crowns prepared using a new dental crown fabrication technique: laser-sintered Co–Cr crowns. J Prosthet Dent 2009;102:253–9.

[17] Kunii J, Hotta Y, Tamaki Y, Ozawa A, Kobayashi Y, Fujishima A, et al. Effect of sintering on the marginal and internal fit of CAD/CAM-fabricated zirconia frameworks. Dent Mater J 2007;26:820–6.

[18] Lombardas P, Carbunaru A, McAlarney ME, Toothaker RW. Dimensional accuracy of castings produced with ringless and metal ring investment systems. J Prosthet Dent 2000;84:27–31.

[19] Persson A, Andersson M, Oden A, Sandborgh-Englund G. A three-dimensional evaluation of a laser scanner and a

touch-probe scanner. J Prosthet Dent 2006;95:194–200.
[20] Witkowski S, Komine F, Gerds T. Marginal accuracy of titanium copings fabricated by casting and CAD/CAM techniques. J Prosthet Dent 2006;96:47–52.
[21] Tan PL, Gratton DG, Diaz-Arnold AM, Holmes DC. An in vitro comparison of vertical marginal gaps of CAD/CAM titanium and conventional cast restorations. J Prosthodont 2008;17:378–83.
[22] McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J 1971;131:107–11.
[23] Bruce RW. Evaluation of multiple unit castings for fixed partial dentures. J Prosthet Dent 1964;14:828–43.
[24] de Oliveira Correa G, Henriques GE, Mesquita MF, Sobrinho LC. Over-refractory casting technique as an alternative to one-piece multi-unit fixed partial denture frameworks. J Prosthet Dent 2006;95:243–8.
[25] Jemt T. Three-dimensional distortion of gold-alloy castings and welded titanium frameworks. Measurements of the precision of fit between completed implant prostheses and the master casts in routine edentulous situations. J Oral Rehabil 1995;22:557–64.
[26] Traini T, Mangano C, Sammons RL, Mangano F, Macchi A, Piattelli A. Direct laser metal sintering as a new approach to fabrication of an isoelastic functionally graded material for manufacture of porous titanium dental implants. Dent Mater 2008;24:1525–33.
[27] Akova T, Ucar Y, Tukay A, Balkaya MC, Brantley WA. Comparison of the bond strength of laser-sintered and cast base metal dental alloys to porcelain. Dent Mater 2008;24:1400–4.
[28] Samet N, Resheff B, Gelbard S, Stern N. A CAD/CAM system for the production of metal copings for porcelain-fused-to-metal restorations. J Prosthet Dent 1995;73:457–63.
[29] Besimo C, Jeger C, Guggenheim R. Marginal adaptation of titanium frameworks produced by CAD/CAM techniques. Int J Prosthodont 1997;10:541–6.
[30] Fransson B, Oilo G, Gjeitanger R. The fit of metal–ceramic crowns, a clinical study. Dent Mater 1985;1:197–9.
[31] Takahashi T, Gunne J. Fit of implant frameworks: an in vitro comparison between two fabrication techniques. J Prosthet Dent 2003;89:256–60.
[32] Marker VA, Miller AW, Miller BH, Swepston JH. Factors affecting the retention and fit of gold castings. J Prosthet Dent 1987;57:425–30.
[33] Papazoglou E, Brantley W, Johnston W. Evaluation of high-temperature distortion of high-palladium metal–ceramic crowns. J Prosthet Dent 2001;85:133–40.