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ORIGINAL ARTICLE

The effect of framework fabrication technique on the fit accuracy of full arch screw retained implant supported prostheses

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KEYWORDS

Implant-supported framework;
Cobalt-chromium;
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Milling

Abstract *Purpose:* The purpose of this study was to compare the accuracy of fit of Co-Cr full arch screw-retained implant-supported fixed dental prosthesis fabricated among three different methods: conventional casting, milling, and additive manufacturing technology.

Materials and methods: A master model of a completely edentulous mandible with five internal connection implants was utilized. Thirty full arch Co-Cr screw-retained implant-supported frameworks were fabricated by three different methods: conventional casting, milling, and additive manufacturing (AM) technology. The marginal fit was measured using a coordinate measuring machine in x-, y-, and z-axes, as well as the three-dimensional discrepancy. The casting group were measured twice: before the adaptation procedure and again after the adaptation procedure (sectioning and laser welding). For comparisons of marginal fit of frameworks between different groups one-way analysis of variance and Games Howell test was used. Paired *t*-test was used to compare cast frameworks before and after adaption.

Results: There were statistically significant differences in marginal fit and width distortion between groups ($P < .05$). The mean of total distortion of each group was 94.6 µm (SD 50.5 µm) for casting group before adaptation, 92.44 µm (SD 49.6 µm) for casting group after adaptation, 71.4 µm (SD 37.2 µm) for additive manufacturing group, while for the milling group the total distortion was 50.1 µm (SD 27.5 µm).

Conclusion: Full arch screw-retained implant-supported frameworks fabricated with any of the three fabrication techniques using cobalt-chromium material exhibited acceptable marginal fit.

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Milling fabrication technique showed the most accurate marginal fit. Adaptation procedure for the cast group has significantly improved the marginal fit.

1. Introduction

Osseointegrated dental implants have been used successfully in the treatment of partial and complete edentulism (Branemark et al. 1977; Adell et al. 1981; Zarb and Schmitt 1990). Many types of prostheses have been used in the treatment of edentulous patients and have evolved with the introduction of computer-aided design/computer-assisted manufacturing (CAD/CAM) technology (Papaspyridakos et al., 2014). Implant-supported fixed dental prosthesis has been shown to be a good restoration option for edentulous ridges with long-term survival rates that exceed 96% survival after 10 years (Brinemark et al. 1983; Papaspyridakos et al. 2014).

The precision of fit of screw-retained implant-supported prostheses is one of the most essential criteria for the success of the implant-supported restorations (Goll, 1991; Al-Fadda, Zarb, and Finer 2007).. Since the introduction of screw-retained implant-supported prostheses, concerns that misfitting frameworks introduces strain and tension to the prosthesis and the *peri*-implant marginal bone, and may increase the risk for complications, have been discussed (Jemt and Hjalmarsson 2011; Hjalmarsson 2009). It has been proposed that misfitting frameworks can result in mechanical failures of prostheses and implant systems, or biologic complications of tissues surrounding the implant (Joseph Y. K. Kan et al., 1999).

Each step in fabricating an implant-supported prosthesis can influence the accuracy of fit between the implant's abutment and the final prosthesis (Hjalmarsson et al., 2010). These steps include implant alignment, impression technique, materials used, framework design and dimensions, fabrication technique and clinician/technician experience. Misfit can also occur in any dimension (x-, y-, and z-axis) (Joseph Y. K. Kan et al. 1999; Almasri et al. 2011). Implant-supported fixed dental prostheses were traditionally fabricated by lost wax casting technique. This technique, however, includes many laboratory steps that may increase chances of errors causing marginal fit discrepancy (Hjalmarsson, 2009; Marcela & Gomes, 2019).

In order to enhance implant framework fit, several materials and fabrication techniques have been proposed, either by the addition of refinement steps or the elimination of certain fabrication steps (Abduo et al., 2011). Addition refinement steps include sectioning and soldering/ laser welding, spark erosion with an electric discharge machine (EDM) and bonding the framework to prefabricated cylinders. In contrast, with CAD/CAM and other rapid prototyping technologies, framework fit has been improved by the elimination of certain fabrication steps such as waxing, investing, and casting (Abduo et al., 2011). Implant-supported frameworks have been successfully fabricated with CAD/CAM using variable span lengths and materials (Delucchi et al. 2021; Katsoulis et al. 2017). The vertical marginal fit of Implant-supported frameworks made with the CAD/CAM technology demonstrated significantly better fit than the conventional cast Co-Cr frameworks (Araújo et al., 2015; Drago et al., 2010; De França et al., 2014; Mundathaje et al., 2014). Accordingly, conventional cast Co-Cr frameworks may be replaced with well-engineered and accurate frameworks produced by CAD/CAM technology (Papadiochou & Pissiotis, 2017).

Frameworks for implant-supported fixed dental prostheses are made using a variety of metal alloys ranging from high noble alloys to titanium or base metal alloys (Delucchi et al., 2021; Teigen & Jokstad, 2012). Gold alloys have been considered the gold standard dental material used in fixed dental prosthesis due to their biocompatibility and ductility (Kassapidou et al., 2017). Due to the high cost of noble metal alloys, however, several alternatives have been proposed (Teigen & Jokstad, 2012). Recently, with CAD/CAM technology Co-Cr alloys have been presented as an alternative framework option because of their cost efficiency and favorable mechanical properties (Hjalmarsson et al. 2010; Abduo 2014).

CAD/CAM technology includes subtractive manufacturing and additive manufacturing. Subtractive manufacturing technology is performed by computer numeric controlled (CNC) milling machines that use burs to cut material blocks to the desired restoration shape. Implant-supported Co-Cr frameworks can be produced by milling wax then casting, or milling hard blocks (hard presintered Co-Cr alloy blocks), or soft milling (soft non-presintered Co-Cr material). In soft milling the material is milled in a "green state" then sintered to full density in a sintering furnace with high temperature (1300 °C) under an argon protective gas atmosphere. This allows for milling with less time and cost (Vojdani et al., 2016).

Additive manufacturing (AM) was first introduced by Charles Hull in 1986. It is defined by the American Society for Testing Materials (ASTM) as the "process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining," (Grant et al., 2016). The additive metal fabrication technology that is commonly used in dentistry is called powder bed fusion. It has three different methods: selective laser sintering (SLS), selective laser melting (SLM) and electron beam melting (EBM) which differ in the energy source and binding mechanism (Konieczny et al., 2020; Yasa, 2021). SLM machines use high-energy fiber laser to selectively melt and fuse fine metal powder layer by layer forming the 3D structure (Revilla-León et al., 2019; Yasa, 2021). The early 3D structures where pours with poor quality. However, with speed advancement in the sintering technology, the current machines replaced the early porous and rough samples with better quality and good physical properties compared to traditional casting methods (Barazanchi et al., 2017).

Compared with subtractive manufacturing, additive manufacturing provides much more flexibility in material utilized and fabricated structures' geometry, it also produces less material waste (Barazanchi et al., 2017). Regarding the marginal fit, however, a systematic review showed that restorations fabricated with milling technology have better marginal adaptation than restorations fabricated with AM technology (Papadiochou & Pissiotis, 2017). Other studies presented better marginal fit for frameworks fabricated with AM technology compared to milling (Örtorp et al., 2011; Svanborg et al., 2018).

Different methods for measuring misfit have been proposed. Coordinate Measuring Machine (CMM) is one of the most advanced techniques for measuring marginal and internal fit of restorations. CMM measures 50 or more points along both the implant abutment and framework surfaces in a circular pattern. The extensive number of points results in a more detailed representation of the amount of vertical gap (Alfadda, 2014). Furthermore, CMM doesn't require seating the framework in the working cast which provides thorough accessibility to prosthesis margins.

Studies on Co-Cr screw-retained implant-supported frameworks fabricated by AM technology measured by CMM have shown 3D marginal discrepancy ranging from 15.3 µm to 73.7 µm (Revilla-León et al., 2020; Revilla-León et al., 2019; Svanborg et al., 2018). Other studies examined Co-Cr screw-retained implant-supported frameworks fabricated by milling CNC technology and have shown the 3D marginal discrepancy to range from 17.8 µm to 54.7 µm (Paniz et al., 2013; Revilla-León et al., 2020; Svanborg et al., 2015). Each study, however, used different parameters and design making comparison difficult. Studies assessing the precision of fit of Co-Cr full arch screw-retained implant-supported fixed dental prosthesis fabricated using AM technology compared with CNC milling technology and conventional casting technique are limited.

The aim of this study was to compare the accuracy of fit of Co-Cr full arch screw-retained implant-supported fixed dental prosthesis fabricated by three different methods: conventional casting, milling, and AM technology. The null hypothesis is that there is no difference in the fit of Co-Cr full arch screw-retained implant-supported fixed dental prosthesis fabricated by conventional, milling, or AM technology.

2. Materials and methods

This in vitro study aimed to evaluate the 3-dimensional accuracy of fit of full arch Co-Cr implant-supported fixed prosthesis frameworks that was fabricated by 3 different manufacturing techniques. A power calculation was conducted using software (Minitab v14.0; Statistical Solutions Ltd). Ten specimens for each tested technique were deemed adequate to obtain a Type I error rate of 5% (α = 0.05) and a power of 93% to detect a difference among the three fabrication techniques. Thirty Co-Cr frameworks were fabricated using three different techniques; conventional casting (Group 1 before adaptation and Group 2 after adaptation), CNC-Milling technology (Group 3) and AM technology (Group 4).

2.1. Fabrication of master model

A clear acrylic material resin (Orthodontic resin clear; DENTSPLY international, USA) model of a completely edentulous mandible was fabricated using a special silicone mold of the mandible. A tooth set-up for complete denture (CD) was created using prefabricated acrylic teeth to fabricate a template to guide implant placement in this model. Five parallel holes in the positions of tooth # 35,33,43,45 (FDI notation) and midline were drilled using an implant drill and a paralometer with their centers approximately 12 mm apart. Five internal connection implants (Bone Level RC, Straumann®, Basel, Switzerland) were stabilized temporarily inside the holes using long implant driver (Straumann® SCS Screwdriver, Basel, Switzerland) mounted in the paralometer and poly vinyl siloxane (PVS) material (Putty genie rapid set, sultan health care, Germany) to temporarily stabilize the implants in position. This master model was used for the fabrication of all frameworks (Fig. 1). Screw retained abutments (022.4745 RC Screw retained abutment, Straumann®, Basel, Switzerland) were hand screwed onto the implant fixtures in the master model using occlusal screw. Then full arch screw retained implant frameworks were fabricated.

2.2. Scanning the master model and teeth set up

The master model and the correspondent CD was digitized using a laser model scanner (S600 ARTI Scanner, Zirkonzahn, Germany) following the manufacturer's protocol. The master model was scanned by connecting implant impression scan bodies to the screw retained abutments on the master model by hand tightening. Another scan was performed with the CD on position on the master model, to be used as a guide for framework design. The model was coated with a special paint to facilitate scanning (CAD CAM spray, NHT, Latavia). The model scanner was a fully automated optical structured-light scanner with two high-resolution high-speed cameras. The two axes of movement generated digital point cloud surfaces that could be exported as Stereolithography (STL) files. The framework design was done using (Zirkonzahn, Germany) software, based on the CD tooth arrangement (Fig. 2).

2.3. Fabrication of reference framework

One full arch screw-retained Co-Cr implant framework was fabricated using additive manufacturing technology (AM) and was considered the reference framework. This framework was fabricated to fit passively on the implants and used as a reference for all other frameworks' measurements. To ensure

Fig. 1 Mandibular master model with five screw retained abutment in specific teeth positions.

that the framework fits passively on the acrylic model, the implants were retrieved from the master model and assembled into the reference framework. The implant-framework assembly was fitted back into the prepared holes located in the acrylic master model and permanently stabilized in position using the same acrylic resin material (Fig. 3). In order to standardize all frameworks dimensions, the same CAD model (STL file) was used to fabricate all the frameworks' specimens.

2.4. Fabricating the conventional cast group frameworks

The frameworks (n = 10) of the first group were cast with the lost wax technique. Using the same STL file, the wax pattern framework was milled from wax milling blocks (Fig. 4) and then cast to metal Co-Cr (Wirobond 280, Bego, Germany) (60.2% Co, 25% Cr, 4.8% Mo, 2.9 % Ga, Si and Mn) using the conventional casting technique. One experienced laboratory technician with over 10 years of experience fabricated all the frameworks, using the same equipment and materials. Each wax pattern was fitted in the model and evaluated for any errors prior to casting. The wax patterns were sprued with wax (wax wire, REF 30813, FINOWAX, Germany). A round wax sprue former was attached to the wax pattern framework and mounted on a crucible former base. The pattern and the sprue formers were treated with a surface tension reducing agent (Hera SWE 2000, KULZER, Germany).

The patterns were invested in ringless mold (Rapid-Ringless-System, Bego, Germany) size 6 (∅ 2″). The patterns were vaccum-invested with phosphate-based investment (Bellavest® SH, Bego, Germany) at a ratio of 160 g powder to 30 ml liquid and 10 ml of water. After the investment material was set according to manufacturer instruction, wax pattern was burnt out in an oven (Miditherm 100 MP, Bego, Germany) following the recommended thermal cycle at 950C for 60 min. It was then positioned in the casting machine (LUKA-CAST S, Lukadent, Germany). The molten Co-Cr alloy was injected into the mold under vacuum pressure following the manufacturer instructions.

After casting, the investment cylinders were allowed to cool for at least 2 h before divesting. The frameworks were divested and sandblasted with 250 μm particle aluminum oxide (Al2O3) stream (Korox® 250, Bego, Germany) at a pressure of 5 bars and glass beads (Perlablast®, Bego, Germany) at pressure of 2 bars. Sprue formers and small nodules were removed under magnification 10 X using sharp tungsten carbide burs with a rotary speed of about 30,000 rpm without cooling water. Frameworks were inspected under a microscope (Renfert, Germany). Distorted frameworks (large voids or numerous porosity) that resulted from inaccurate casting were excluded and a new framework was fabricated following the same fabrication protocol.

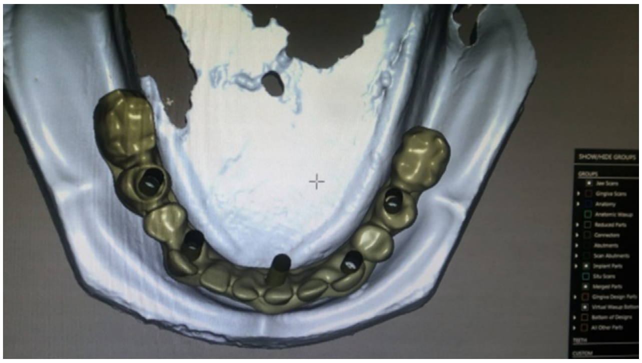

Fig. 2 Framework designed using computer-aided design software (CAD).

Fig. 3 Reference Co-Cr framework fabricated using additive manufacturing technology.

The frameworks were numbered from 1 to 10 and named cast (before adaptation) group. Marginal fit measurements were performed then the casted frameworks were sectioned, and laser welded using (LaserStar T plus, Bego, Germany) to adapt the frameworks to the maser cast, then measurements were achieved again and named cast (after adaptation) group.

2.5. Fabricating the CNC-Milled group frameworks

The frameworks (n = 10) were milled using the same STL file. A block of Co-Cr alloy (Ceramill Sintron, amanngirrbach, Austria) that composed of (66% Co, 28% Cr, 5% Mo, $<1\%$ Mn, $<1\%$ Si, $<0.5\%$ Fe) was mounted in a CNC milling machine. The milling machine was set by 5 degrees of freedom (CADCAM M5, Zirkonzahn, Germany) with speed

Fig. 4 Milled wax pattern framework ready for casting.

up to 50,000 rpm. The Co-Cr frameworks were then finished and polished by one dental technician.

2.6. Fabricating the AM group frameworks

The frameworks (n = 10) were fabricated by AM technology using the same STL file used for reference framework. All frameworks were fabricated by AM technology using the Mlab cusing machine (CONCEPTLASER, Germany), which has a fiber laser with 100 W laser power and is suitable for processing precious and non-precious metals. The frameworks were fabricated using Co-Cr alloy powder (Starbond Easy Powder 30, Scheftner, Germany) that composed of (61% Co, 27.5% Cr, 8.5 % W, 1.6% Si and < 1% C, Fe, Mn). The frameworks were then finished and polished according to the manufacturer's recommendations by one dental technician.

2.7. Assessment of the precision of framework fit

In order to measure the three-dimensional distortion of the frameworks to their respective implants, a Coordinate Measuring Machine (CMM) (ACCURA, Carl Zeiss Industrial Metrology, Germany) was used (Fig. 5). All frameworks were numbered and presented randomly to eliminate any measurement bias. Measurements were all performed by one trained technician in the department of industrial engineering, college of engineering, at King Saud University. Prior to each measurement session, the machine was calibrated against a reference sphere of known diameter (2.0 mm) according to the manufacturer instructions. A stylus system with a ball diameter = 1 mm and effective measuring length = 11 mm was used.

Positions of the 5 implants in the master model were measured and calculated as to their three-dimensional spatial orientation. Positions were then matched digitally to the measured positions of framework cylinders. The frameworks and implants were measured with 20 points in a circular pattern. Each point had a positional coordinate in x-, y-, and z-axes and a total distortion was obtained. To get a better stabilization in the measurement machine the full arch frameworks were fixed in mold fabricated by plaster for each framework individually (Fig. 6).

The reference framework was measured as well and the obtained measurements were considered the reference for the tested specimens. Three repeated measurements of the reference framework were done to get the standard deviation. which represented the reproducibility of the machine. To measure the three-dimensional distortion between the frameworks and the respective implant, the coordinate system (base alignment) for the implant fixtures was established as follows: (1) flat 3 constrains spatial rotation (i.e., pitch and roll) setting + Z axis. It also constrained the Z translation setting Z = 0; (2) the line segment joining the intersection of Cone l - Flat 1 and the intersection of Cone 5 - Flat 5 constrains planar rotation (i.e., yaw) setting the + X axis; and, finally, (3) the intersection of Cone 3 - Flat 3 constrains X and Y translation setting X = 0 and Y = 0. The base alignment for the frameworks was established as follows: (1) flat 3 constrains spatial rotation (i.e., pitch and roll) setting -Z axis. It also constrains the Z translation setting Z = 0. (2) The line segment joining the intersection of Cone l - Flat 1 and the intersection of Cone 5 - Flat 5, constrains planar rotation (i.e., yaw) setting the + X axis. And, finally, (3) the intersection of Cone 3 - Flat 3 constrains X and Y translation setting X = 0 and Y = 0. Each point had a positional coordinate in x-, y-, and z-axes and a total distortion was calculated. The actual and nominal values for ×, y, and z were registered together with the corresponding deviations in each axis. The total distortion was measured as the signed square root (X-Dev*X-Dev + Y-Dev*Y-Dev + Z-Dev*Z-Dev), which represented the total deviation of each point in three dimensions. The Zeiss CMM was linked to a computer, and the obtained data were analyzed using a standard measuring software (Calypso, Carl Zeiss, Germany).

2.8. Statistical analysis

After calculating the mean of the readings from frameworks' specimens, each framework was presented by one number. Normality was satisfied using Shapiro-Wilk and Kolmogorov-Smirnov tests. A paired *t*-test was used to com-

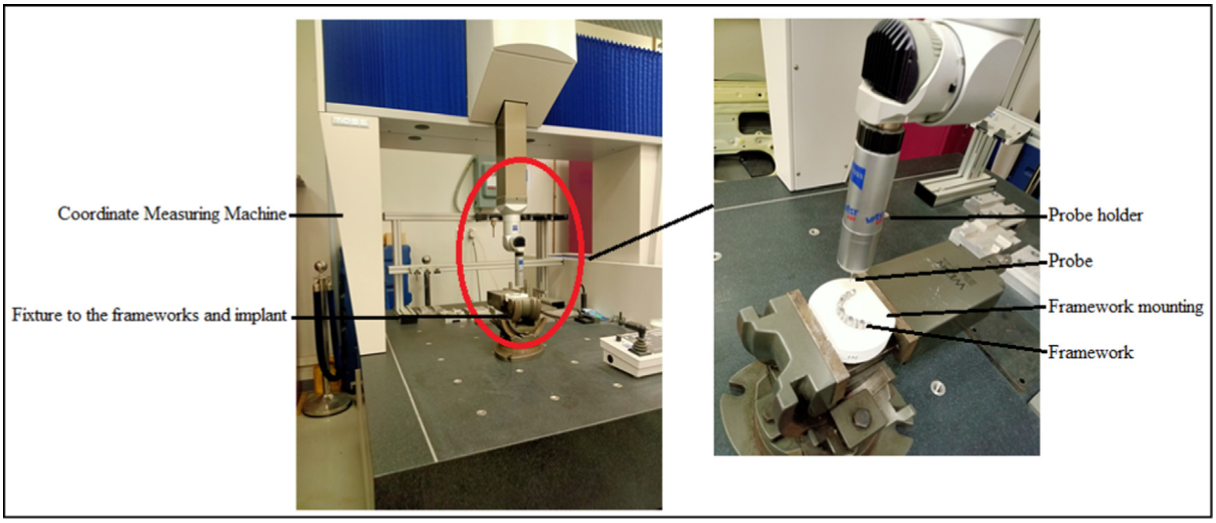

Fig. 5 Measurement set up Zeiss ACCURA coordinate measuring machine.

Fig. 6 Framework mounted to facilitate CMM measurement.

pare cast frameworks before and after adaption. For comparisons of marginal fit of frameworks between different groups (except cast frameworks before adaptation) one-way analysis of variance (ANOVA) and Games Howell test were used. To assess the expansion of the frameworks the width was measured (the distance between implant position 1 and 5 in x-axis), then compared to the distance between the same implant position in the master model. Statistical analysis was performed by using Statistical Package for the Social Sciences (SPSS) version 25 software (SPSS Inc., Chicago, IL, USA). Raw data were entered in Microsoft Excel (Microsoft 2020), units were converted from millimeter to micrometer before exporting the data to SPSS. Descriptive analysis for the discrepancies (means, standard deviations [SDs], maxima, minima) were calculated to compare the measurements of all groups. Any tests that yielded a *p*-value of 0.05 or less was considered statistically significant at α level of 0.05.

3. Results

The mean distortion of each group of frameworks are described in (Table 1) and (Fig. 7). The mean total distortion was 94.6 µm (SD 50.5 µm) for casting group before adaptation, 92.44 µm (SD 49.6 µm) for casting group after adaptation, 71.4 µm (SD 37.2 µm) for the AM printed group, and 50.1 µm (SD 27.5 µm) for the CNC-milled group.

There were statistically significant differences in distortion between groups ($P < .05$) as presented in (Table 2). Paired *t*-test showed significant difference between cast group frameworks before and after adaptation ($P < .05$) in horizontal (x- and y-axes) and total distortion. However, the vertical distortion (z-axis) and the width showed no statistically significant difference as presented in (Table 3). The CNC-milled framework group showed overall less distortion compared to the AM and the casting groups in all the three axes. The least amount of distortion in CNC-milled group was in the x-axis. For the AM and casting group, however, the least amount of distortion was in the y-axis. Vertical distortion (z-axis) for all groups was found to be greater than the horizontal distortion (y- and x-axes).

Distortion of frameworks' width compared to the master model is presented in (Table 4). There was statistically significant differences between groups ($P < .05$). There was a difference in the direction of distortion; the cast group presented a contraction of width in (x-axis), while the AM and CNC group presented expansion in (x-axis).

Table 1 Mean distortion of frameworks in (µm).

Axes	Group	Mean	Std. Deviation
ΔX	Cast (before adaptation)	53.10	31.66
	Cast (after adaptation)	51.72	31.30
	AM	39.91	24.52
	CNC	21.74	18.08
ΔY	Cast (before adaptation)	51.16	32.40
	Cast (after adaptation)	49.33	31.47
	AM	31.88	24.78
	CNC	28.12	18.64
ΔZ	Cast (before adaptation)	55.44	30.72
	Cast (after adaptation)	54.82	30.54
	AM	45.13	25.22
	CNC	30.76	19.72
Total Distortion	Cast (before adaptation)	94.60	50.48
	Cast (after adaptation)	92.44	49.62
	AM	71.43	37.24
	CNC	50.09	27.52

4. Discussion

The aim of the present study was to compare the accuracy of fit of Co-Cr framework for screw-retained implant-supported fixed dental prosthesis fabricated by casting, milling, and AM technology. All frameworks presented an amount of misfit with varying degrees, and none of them showed an accurate marginal fit. Accordingly, the hypothesis that there would be no difference in fit of Co-Cr screw-retained implant-supported frameworks fabricated by casting, milling, and AM technology was rejected.

Achieving an accurate implant framework with passive fit is difficult and inevitable degree of inaccuracy would always be present and is difficult to avoid (Abduo et al., 2011). This is because of the many steps that included in framework fabrication techniques. In this study, many steps were eliminated to test the effect of the fabrication technique alone. Accordingly, one cast and one design were used for fabricating all the frameworks. This allowed for standardization of all specimens and the elimination of any cofactors other than the fabrication technique.

Each fabrication technique has several factors that could affect accuracy of restoration. In conventional casting, many laboratory steps are included, which increase the chance of errors (Hjalmarsson, 2009; Marcela & Gomes, 2019). In this study, however, the wax pattern framework was milled with milling wax instead of conventional wax pattern fabrication. This reduced the technician errors and improve the fit accordingly (Ghodsi et al., 2018; Örtorp et al., 2011). Although the casting group showed the largest amount of misfit even after sectioning and laser welding, it is still within the clinical acceptable range suggested by earlier publications, from 10 up to 150 µm for the vertical distortion (Branemark, 1983; Jemt, 1991; Svanborg et al., 2018). Few studies were carried out on Co-Cr implant frameworks fabricated by casting techniques using the same design and measuring technique. Studies on casting

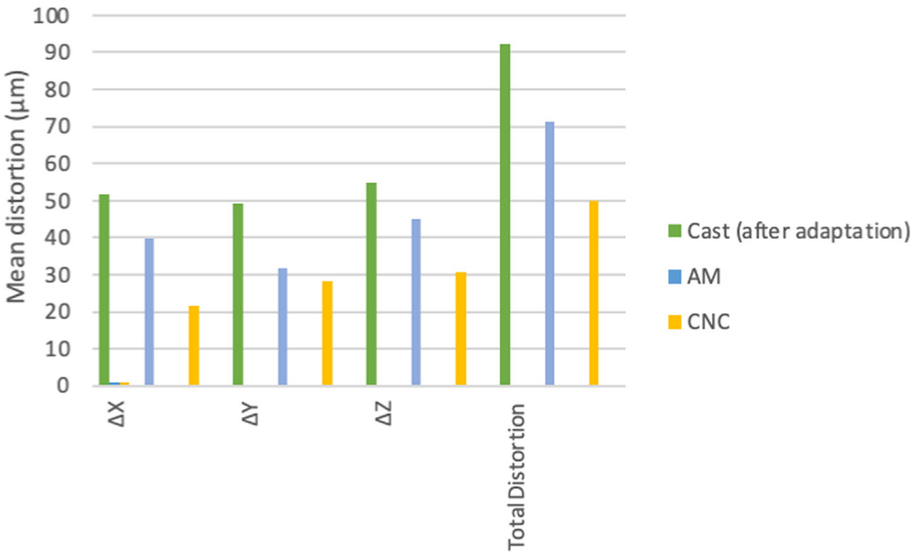

Fig. 7 Mean distortion (μm) of frameworks of all groups in different axes.

Table 2 Multiple comparison test (Games Howell) between groups.

	Cast (after adaptation)	AM	CNC
Cast (after adaptation)	–	0.048*	0.000*
AM		–	0.004*
CNC			–

* There is a significant difference between groups *p-value* < 0.05.

Table 3 Paired *t*-test between cast frameworks before and after adaptation.

Axes	Group	P-value
X	Cast (before adaptation) Cast (after adaptation)	0.001*
Y	Cast (before adaptation) Cast (after adaptation)	0.000*
Z	Cast (before adaptation) Cast (after adaptation)	0.320
3D	Cast (before adaptation) Cast (after adaptation)	0.000*
Width	Cast (before adaptation) Cast (after adaptation)	1.000

* There is a significant difference between groups *p-value* < 0.05.

Co-Cr framework showed an acceptable level of fit, but usually required an additional fit enhancement procedure such as sectioning and soldering or laser welding, etc. (Abdel-Azim et al., 2014; Örtorp et al., 2011). In this study, the adaptation procedure significantly improved the marginal fit in the horizontal (x- and y- axes) dimension and the total distortion but not in the vertical (z-axis) dimension.

In this study, Co-Cr alloy was used in framework fabrication for all groups. Previous studies showed comparable performance of Co-Cr alloy in regard to distortion with Titanium (Ti) and gold alloys. Svanborg et al. (2015) compared full arch screw-retained implant-supported frameworks milled with Ti and Co-Cr, by measuring the marginal gap with CMM and found a 3D marginal gap of 9 μm and 17.8 μm respectively, and the vertical distortion was comparable. They concluded that the difference was of no clinical significance and the fit of both was considered good. Paniz et al. (2013) compared full arch screw retained implant-supported frameworks milled with Ti and Co-Cr to conventional cast gold frameworks and found that Ti and Co-Cr showed marginal discrepancies 26 μm less than cast gold alloy frameworks 49 μm. Regarding the clinical performance of Co-Cr framework, a retrospective study of a patient sample with implant-supported fixed prostheses frameworks made from Co–Cr or type 3 gold monitored for up to 18 years, demonstrated comparable results (Teigen & Jokstad, 2012). Therefore, Co-Cr alloy may be a reasonable alternative for fabricating implant frameworks with less cost and favorable mechanical properties (Hjalmarsson et al., 2010).

Table 4 Mean width in (mm) of frameworks compared to the master model.

	N	Width difference	Mean	SD	*p-value*
Cast (after adaptation)	10	−0.12	34.17	0.05	0.00*
AM	10	0.11	33.94	0.01	0.00*
CNC	10	0.06	33.99	0.03	0.00*

* There is a significant difference *p-value* < 0.05.

Although agreement on the clinically acceptable levels of misfit has not yet been reached, it is better to target to the best possible implant framework fit. With the development of CAD/CAM technology improving the accuracy of fit has increased. This is because many steps are eliminated (e.g., wax up, investing, etc.) which reduce the possibility of technician errors. This is consistent with the results of this study which show better marginal fit for the CAD/CAM group compared to the cast group. However, there are other factors that could affect the accuracy of digitally fabricated frameworks such as the type of machine used, type of material, frequency of burs replacement, technician experience, etc.

Revilla-León et al. (2019) compared three different SLM technologies in fabricating full arch implant-supported Co-Cr frameworks by measuring the marginal fit with the CMM machine. They reported a mean 3D marginal discrepancey ranging from 47.3 µm and 73.7 µm which is comparable to results obtained in the present study. In the present study the CNC milling group showed significantly less amount of total distortion 50.1 µm (SD 27.5 µm), compared to the AM group 71.43 µm (SD 37.24 µm). A possible explanation is the heat generated by laser in the AM group. In addition, microroughness may happen with solidification of each layer of metal which may lead to overall discrepancy of the framework.

Revilla-León et al. (2020), however, compared full arch Co-Cr implant frameworks fabricated by AM and CNC milling technology, and found no significant diffference in the mean total distortion between the two fabrication techniques with 54.1 ± 7.7 µm for the AM and 54.7 ± 9.8 µm for the CNC group. Furthermore, Örtorp et al. (2011) compared the fit of three-unit Co-Cr FDPs fabricated by 4 methods: conventional lost-wax method, milled wax with lost-wax method, milled Co–Cr, and AM direct laser metal sintering. They found the best marginal fit was with the AM group. However, the frameworks were cement-retained and a stereomicroscope was used for marginal gap measurement. According to Svanborg et al (2018) printed screw-retained implant-supported frameworks in Co-Cr and Ti had better percision compared with milled frameworks using the same material. This does not coincide with the results of the present study. This could be because the implant mating surfaces were milled after printing in Svanborg study. Differences in results among studies can be attributed to the wide variation in study design and parameters used such as the type of machine, material composition, implant position and angulation.

In this study vertical distortion (z-axis) for all groups were found to be greater than the horizontal distortion (y- and x-axes). This can be explained by the direction of metal contraction. It is still, however, within the clinical acceptable range. In this study, CMM measuring machine was used, which is a programmable, flexible measuring instrument used to collect and report on dimensional data of manufactured components. It is a device that measures the geometry of physical objects by sensing discrete points on the surface of the object with a highly accurate probe. CMM has been used successfully in measuring the marginal fit of different types of prosthesis (Al-Fadda et al., 2007; Hjalmarsson et al., 2010; Jemt & Hjalmarsson, 2012; Örtorp & Jemt, 2003; Revilla-León et al., 2020; Svanborg et al., 2018). However, one of the possible limitations of this study is that the frameworks are fitted digitally by software which could include negative values under representing the true amount of misfit (Jemt & Hjalmarsson, 2012). Thus, comparing the results of this study with other studies should be made with caution.

Further studies are recommended in the field of different machines calibrations that are suitable for dental use. In addition, conceding the use of Nano technology to produce more accurate metal powder and/or blocks to enhance accuracy of the dental prosthesis framework is suggested.

5. Conclusion

Within the limitations of this in-vitro study the following conclusions can be made:

1. Full arch screw retained implant-supported Cr-Co frameworks fabricated with casting, milling, or AM technology techniques exhibited acceptable marginal fit.
2. There are statically significant differences between groups and CNC-milled frameworks showed the most accurate marginal fit.
3. Marginal fit was significantly improved after the adaptation procedure for the cast group.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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