Marginal Fit and Internal Adaptation of Monolithic Zirconia 3-Unit Fixed Dental Prostheses: In-Vitro Study

by

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MSc, University of Western Australia, 2015

BDS, Riyadh Elm University, 2011

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

The Faculty of Graduate and Postdoctoral Studies

(Craniofacial Science)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

August 2021

The following individuals certify that they have read, and recommend to the Faculty of Graduate and Postdoctoral Studies for acceptance, the thesis entitled:

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Submitted by Nuha Abubaker Alkaff in partial fulfillment of the requirements for the degree of Master of Science

in Craniofacial Science

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Abstract

Objectives: To compare marginal fit and internal adaptation of monolithic zirconia (MZ) 3-unit fixed dental prostheses (FDPs) fabricated using two workflows: a full-chairside computer aided design/computer aided manufacturing (CAD/CAM) one (FCH) and a lab CAD/CAM one (LAB).

Methods: Teeth #14 and #16 were prepared for MZ 3-unit FDP on an ivorine typodont. A total of 30 MZ 3-unit FDPs was fabricated using two processes: FCH and LAB. A CEREC Primescan intraoral scanner was used in both workflows to digitize the typodont model. FCH FDPs (n=15) were designed using CEREC SW 4.5.1 and milled using CEREC MC X. LAB FDPs (n=15) were designed using Exocad and milled using Zirkonzhan 600/V3 milling chamber. A fast-sintering protocol was used in both groups. A dual-scan technique was utilized to assess the cement space. The fit was evaluated at systematically selected areas: occlusal surface (OC), axial wall (AX) and margin (MA). Statistical analysis of the results was performed using univariate analysis of variance (ANOVA) with Scheffè post hoc test (P=0.05).

Results: The measurements in FCH and LAB groups are within the clinically acceptable marginal and internal fit. The MA, AX and OC fit at retainer 14 of the FCH FDPs is 87.60 ±30. µm, 104.80 ±25.84 µm and 158.53 ±25.08 µm respectively, and of the LAB FDPs is 105 ±23.19 µm, 117.60 ±20.48 µm and 146.53 ±19.27 µm respectively. The MA, AX and OC fit at retainer 16 of the FCH FDPs is 67.40 ±26.50 µm, 94.53 ±15.51 µm and 141.53 ±34.34 µm respectively, and of the LAB FDPs is 95.53 ±30.51 µm, 115.47 ±15.66 µm and 138.07 ±20.36 µm respectively. The difference between the two groups is not statistically significant.

Conclusion: The MZ 3-unit FDPs fabricated using FCH have clinically acceptable marginal and internal fit. This verifies the efficiency of FCH workflow in fabricating MZ multi-unit FDPs in a single visit, especially useful for people who cannot attend multiple visits to receive the restoration.

Lay Summary

Full-chairside computer aided design/computer aided manufacturing (FCH CAD/CAM) workflow allows for digital design and manufacturing of any of partial-coverage, full-coverage, single-unit or multi-unit restorations in a single day. The long-term success of such restorations depends, among other things, on their marginal and internal adaptation. In this study, the marginal and internal fit of 3-unit fixed dental prostheses (FDPs) made from monolithic zirconia (MZ) fabricated using FCH CAD/CAM and LAB CAD/CAM workflows were investigated. 3-unit MZ FCH CAD/CAM FDPs were designed and fabricated using CEREC. It was concluded that both workflows produce 3-unit MZ FDPs with clinically acceptable marginal and internal fit.

Preface

This research project was done under the direct supervision of Dr. Nesrine Mostafa. The committee members included Dr. N. Dorin Ruse and Dr. Alan Hannam.

Digital impressions for both FCH and LAB groups were secured by the author. CAD/CAM of the 3-unit MZ FDPs for the FCH group were made by the author, while those for the LAB were made by Key dental laboratory. The author performed all the scanning, subsequent measurements, data collection and analyses independently.

This study did not require approval from the UBC Research Ethics Board as it did not involve the use of any human subjects, animals or biohazardous materials.

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List of abbreviations

AX	**Axial gap**
CAD	**Computer-aided design**
CAM	Computer-aided manufacturing
CEREC	Chairside Economical Restoration of Esthetic Ceramic
DST	Dual-scan technique
FCH	Full-chairside CAD/CAM workflow
FDP	Fixed dental prosthesis
HTML	High Translucent Multi-layered
IG	Internal gap
IQR	interquartile range
LAB	Combined (inLab) CAD/CAM workflow
LS_2	Lithium disilicate
MG	Marginal gap
µm	Micrometer
MZ	Monolithic zirconia
OC	Occlusal gap
PMMA	Poly (Methyl Methacrylate)
PVS	Polyvinylsiloxane
STD	Standard deviation
STML	Super Translucent Multi-layered

USPHS	United States Public Health Service
UTML	Ultra-Translucent Multi-layered
Y-TZP	Yttrium-Tetragonal Zirconia Polycrystals

Acknowledgment

I would like to express my sincere gratitude to my supervisor Dr. Nesrine Mostafa for her valuable guidance, help and support to complete such elaborate project.

I would also like to extend my appreciation to my advisory committee, Dr. N. Dorin Ruse, for his guidance and help with the statistical analysis, and Dr. Alan Hannam, for his input on digital measurements used in this project.

Thanks to my country, the Kingdom of Saudi Arabia, especially the Saudi ministry of education, for supporting me financially to pursue higher education at UBC.

Dedication

I would like to dedicate this thesis to:

The memory of my father, Abubaker Alkaff, who gave me the greatest gift anyone could give another person, he believed in me. All those memories of him teaching me, guiding me and encouraging me made me keep going through the hard times. I really wish he was here to celebrate this achievement with me. Rest in peace dear father.

My mother, Monirah Alkaff, for her continuous prayers, support and encouragement to succeed and be a better version of myself.

My husband, Mohammed Alkaff, and my beloved daughters, Lana and Khadija, for their unconditional love, patience and support during the whole journey.

My brothers, Mohammed, Hussain, Ahmed, Abdullah, Hassan and Ibrahim, and my sisters, Najla and Nada, for their prayers and love.

Chapter 1: Introduction

One of the main requirements of replacing missing dentition in prosthodontics is to use a restorative biomaterial that meets the patient's functional and esthetic needs. The most frequently used materials for tooth-supported and implant-supported fixed dental prosthesis are dental ceramics.[1,2] Lithium disilicate (LS_2) is one of the most popular metal-free and of low thermal expansion ceramic materials used to esthetically restore the dentition.[3] It has shown better performance when replacing the anterior teeth than posterior dentition due to its relatively low mechanical properties (flexural strength and fracture toughness).[4,5] For monolithic LS_2 posterior three-unit fixed dental prostheses (FDPs), various clinical studies have been published presenting survival rate of 88 % after 10 years[6] and 48.1 % after 15 years[7]. This led to the introduction of dense and crystalline ceramics, yttria-stabilized tetragonal zirconia polycrystal (Y-TZP), based on its higher mechanical properties. [8–11]

1.1 Monolithic zirconia

In comparison to other ceramics and metal ceramic restorations, monolithic Y-TZP restorations perform well clinically in the long term[2,12] and do not deteriorate during high artificial ageing.[9,11] However, due to its high opacity, it has inferior optical properties than the other weaker, but esthetic ceramics.[2,12,13] Therefore, clinicians tend to use 3Y-TZP to fabricate core and frameworks of crowns and FDPs and to veneer them with translucent porcelain for esthetic purposes. However, chipping and fracture of the veneering ceramic due to processing-related residual stresses were found to be frequently occurring in veneered zirconia restorations. [14–17] Reports show a 10-year cumulative chipping rate of 37.7 % of the ceramic veneering of zirconia core[18] and a low 10-year success rate of 57 %.[19] Therefore, monolithic zirconia (MZ), with superior esthetic properties, was required to overcome such issues.

The opaque Y-TZP was modified using more yttria content, less Al_2O_3 and higher sintering temperature and/or duration to decrease impurities and grain boundaries that cause less light scattering.[20] However, increasing the sintering temperature and yttria content would increase the cubic content and this would decrease the material's mechanical properties (flexural strength and fracture toughness). There are three kinds of mol % Y-TZP: 3Y-TZP, 4Y-TZP and 5Y-TZP, each with relatively different optical and mechanical properties and, therefore, with varying clinical applications.[20,21]

1.2 Multi-layered monolithic zirconia

Recently, dental companies have developed multi-layered zirconia material to meet patients' esthetic needs. From its name, multi-layered zirconia provides a tooth-like gradual shade, where the incisal part of the restoration is translucent and the cervical part is more chromatic than the middle region. Katana (Kuraray Noritake, Japan) is the first dental company to have introduced multi-layered zirconia system in 3 different types, Ultra Translucent Multi Layered (UTML), Super Translucent Multi Layered (STML), and High Translucent Multi Layered (HTML). These three types exhibit trade-offs between opacity and flexural strength, which differentiate their clinical indications. The flexural strength of UTML, STML and HTML is 460-557 MPa, 748-895 MPa[22] and 1120-1194 MPa, respectively.[21,23] Due to the high flexural strength of HTML, it is recommended for long span FDPs, UTML is recommended for veneers to single crowns and

STML for crowns to 3-unti FDPs. All three types of multi-layered zirconia are available in puck for inLab milling except STML (4Y-TZP), which is also available in block for CEREC chairside milling.[21]

1.3 Full-chairside CAD/CAM

Chairside CADCAM systems are increasing in number. In the last decade, innovations to the in-office CAD/CAM systems and to the associated materials have facilitated a rapid production of a wide range of reliable and predictable esthetic restorations.[24,25] CAD/CAM manufacturing starts with using intraoral scanners (IOS). IOS have been improved in terms of size, speed of acquisition and accuracy. In comparison to the conventional workflow, CAD/CAM workflow reduces human errors while taking the analog impression or fabricating the restorations. It improves patient comfort and it produces the proposed restoration in a shorter period of time, which could be attributed to the smaller number of steps.[26,27] Unlike conventionally layered materials, CAD/CAM material in the form of blank and block is more homogenous and shows less pores and flaws, thus it is more reliable.[28,29]

1.4 Full-chairside CAD/CAM vs Lab CAD/CAM

In-office CAD/CAM has become competitive to lab CAD/CAM. This can be attributed to its ability of producing the proposed restoration in less than one hour. By delivering the restoration on the same day, there is no need for temporization that may increase the chance of reinfection of the prepared abutment tooth. Besides, there are no laboratory or shipping fees and no cross contamination associated with the milling process in the lab.[30] Such workflow would be tremendously useful for elderly patients who have difficulty accessing multiple and long dental appointments.

In-office digital workflow consists of scanning the tooth by an IOS, visualizing the abutment and determining the finish line, designing the restoration on a software (CAD), and then milling the restoration using a chairside milling machine (CAM).[30]

There are few in-office digital systems available in the dental market, such as CEREC (Dentsply, Sirona), Planmeca E4D (Planmeca, USA, Inc.), Glidewell (Glidewell laboratories) and CS solutions (Carestream Dental). The most commonly used and tested full-chairside CAD/CAM system is CEREC, since it is the inventor of this technology. The accuracy of the in-office CEREC workflow has been tested and reported in the literature and showed similar or better results in comparison to that of the traditional workflow.[31–35]

1.5 Marginal fit & Internal adaptation

One of the main criteria that affects the clinical quality, success, longevity, biological and mechanical stability of an indirect dental restoration is its marginal and internal adaptation.[36] The less the marginal gap, the less plaque accumulation, gingival irritation[37], caries and discoloration[38,39]. Marginal gap also exposes the luting cement and leads to its dissolution.[38] The marginal integrity is affected by the processing procedure used and the choice of CAD/CAM system. In addition, the mechanical behavior of tooth-supported restorations, in terms of retention and fracture resistance, should be enhanced by having an accurate internal adaptation.[32,40]

1.5.1 Terminology

Holmes et al.[41] proposed a precise terminology to describe the fit of dental restorations.

- **Internal gap (IG)** is the perpendicular measurement from the internal surface of the casting to the axial wall of the preparation, while the same measurement at the margin is called the **marginal gap (MG)**.
- **Overextended margin** is the perpendicular distance from MG to the crown margin.
- **Underextended margin** is the perpendicular distance from MG to the cavosurface angle of the tooth.
- **Absolute marginal discrepancy (AMD)** can be defined as the angular combination of MG and the extension error (over-extension or under-extension), which represents the distance from the preparation finish line to the restoration margin. It reflects the total crown misfit at that point (vertically and horizontally).

1.5.2 Acceptable marginal discrepancy

Identifying what a clinically acceptable MG for indirect restorations in the literature is difficult. The ideal cement thickness for indirect restorations was found to be 25 μm for type I luting agent (glass ionomer, zinc phosphate, and polycarboxylate cements) and 40 μm for type II luting agent (glass ionomer-resinous hybrid and resin cements), which are difficult to achieve.[42] The clinically acceptable MG was suggested by multiple studies. One study has considered MG of 50 μm to 120 μm as successful, while others have suggested that a less than 100 μm gap is acceptable.[43] Mclean et al.[44] evaluated more than 1000 crowns over a 5-year period and found that the acceptable MG less than 80 μm is difficult to achieve clinically. Moreover, Fransson et al.[45] and McLean et al.[44]

reported that the clinically acceptable MG after cementation should be less than 150 µm and 120 µm, respectively. It is noteworthy that the previously reviewed studies have measured marginal fit for casted restoration. However, a systematic review, which included 183 studies, reported that the fit of ceramic restorations varies widely from (7.5 to 206.3) µm.[42] Such discrepancy could be attributed to lack of coherence regarding the MG definition, different methods employed to evaluate the gap, different fabrication methods (conventional vs. CAD/CAM), different CAD/CAM systems, stage at which the measurements were performed (before/after cementation), and ceramic systems utilized.[42] Recently, another systematic review of 41 studies reported that the average marginal fit of tooth-supported zirconia FDPs ranges widely from 3.6 µm to 206.3 µm.[46] This heterogeneity can be attributed to the use of different CAD/CAM systems results, and even for the same system, there were significant variations owing to variations in the study design. It can also be due to the type of material used, state of sintering, experimental methodology, sample size and span length of FDP.[46] Based on the available evidence, several *in vitro* studies considered MG up to 120 µm to be clinically acceptable for cast and ceramic restorations.[40,47,48] Toward this end, the aim of this chapter is to summarize the current evidence on marginal fit of fixed dental prosthesis (FDPs) and to discuss different variables that could influence treatment outcomes.

1.5.3 Accuracy of full-chairside CEREC CAD/CAM

The marginal and internal fit of different dental restorations fabricated by a chairside CEREC CAD/CAM system have been tested and reported in the literature.[31–35,49–51] Chairside CEREC CAD/CAM system produces full-coverage single crowns restorations of marginal discrepancy (MD) ranges between 25.8 µm and 141.5 µm[31–35] and absolute marginal discrepancy (AMD) of 115 µm[34,35] which coincide with what was reported in the literature[41], while the ranges of internal misfit are: occlusally: 50.1 μm - 285.2 μm, and axially: 40.5 μm - 96.9 μm.[31–35] The reported MD of the crowns made by CAD/CAM system ranges between 50 μm and 100 μm[52–54]. There are numerous factors that play a role in the discrepancy with IOS, including: the type of scanner[55], type of material[56], fabrication method[34], finish line preparation[57], measuring technique[35,55,56,58–60], application of powder before scanning and internal adjustments to the intaglio surface of the restoration[55]. Most of the referenced studies were done for restorations made of ceramic material.

1.5.4 Methods of measuring the marginal gap

Clinical methods for measuring marginal gap

Proper fit of dental restorations can be assessed clinically using a mirror and a dental explorer. In the literature, most of the in-vivo clinical studies have evaluated the marginal discrepancy of fixed dental prostheses using standardized criteria, e.g. United States Public Health (USPHS).[61,62] These criteria are based on surface, colour, anatomic form and marginal integrity (Table 1). There are 4 classifications for marginal integrity: alpha, bravo, charlie and delta. Restorations that fall in the alpha and bravo categories are considered acceptable. Alpha means that the restoration is excellent and meets all the clinical standards, while bravo indicates that the restoration has minor errors but clinically acceptable. Charlie and delta are considered unacceptable and indicate the need of replacement of the restoration to avoid future complications, and immediate removal and replacement of the restoration, respectively.

Table 1. United States Public Health (USPHS)[61,62] criteria for marginal integrity.

Marginal integrity	**Alpha (A)**	No visible evidence of crevice along the margins; no catch or penetration of the explorer.
	Bravo (B)	Visible evidence of crevice and/or catch of the explorer; no penetration of the explorer.
	Charlie (C)	Visible evidence of crevice and penetration of the explorer.
	Delta (D)	Mobile or fracture restoration OR caries contiguous with the margin or the restoration OR tooth structure fractured.

In-vitro methods for measuring marginal gap

In-vivo studies have some patient and technique related challenges, including tooth preparation, impression and cementation technique sensitivity, in addition to saliva contamination and patient compliance.[63] On the other hand, in-vitro experimentation facilitates a standardized set up and provides a reliable testing environment. There are different techniques to measure the marginal fit of FDPs, either destructive methods (such as the cross-sectioning) or non-destructive methods (such as direct viewing, impression replica, profilometry and micro-computed tomography (micro-CT)). Both 2D and 3D analysis are possible with the optical coherence tomography, micro-CT, triple-scan technique and dual-scan technique. The cross-sectional and the silicon replica techniques can make assessments only using 2D analysis.

The cross-sectional method: this is a destructive method where, after cementation, the desired part of the restoration is sectioned and marginal and/or internal gap are measured in horizontal and vertical directions under an optical or electron microscope. It is considered an accurate method since the actual restoration is cut and measured; thus, it allows for precise evaluation of the marginal fit and internal adaptation. However, it cannot be made directly in the oral cavity. It does not allow for repeated assessment of the same specimen before and after cementation or prior to clinical placement and it cannot be used for longitudinal assessment. Moreover, it does not evaluate the overall fit of the restoration since its sectioning plane limits the number of measurements.[64,65]

Direct view technique: It is the most commonly used non-destructive technique that measures the vertical MG under optical or electron microscope. It is cheap and less-time consuming than the other techniques. However, it cannot measure the internal gap, it has difficulty to identify reference measurement points and cannot repeat measurement from the same angle of view. Moreover, it has projection errors, where horizontal and vertical MG or AMG may have been measured based on the angulation of the specimen during measurement.[66]

Optical coherence tomography: It is a non-destructive and non-radiological method where it captures high resolution 2D and 3D images in optical scattering media using coherent light in real-time. It is often used in in vivo studies.[67,68] However, it has difficulty measuring bulky and thick restorations or optical-opaque materials.[69,70]

The silicone replica technique: It is a non-destructive technique. It follows the same protocol of prosthesis cementation, except that light body silicone material is injected instead of cement to duplicate the internal and marginal gap to be measured. The replica is sectioned and measured at different sites. This method has been utilized in many in-vivo studies due to its simplicity, low-cost and ability to be done intraorally.[71] However, there is a chance of tearing the impression material.[72] Moreover, it allows for 2D measurement only.

Profilometry: It is another non-destructive technique where the crown is displayed on its die in the same focal plane, to have a well-defined focus.[73] However, the cement at the MG can only be measured indirectly. In case of sequential analysis, repositioning the sample has to be done carefully to avoid reprofiling inconsistencies.[60]

Micro-computed tomography: It is a non-destructive method where radiography is used to provide high resolution 3D images that enable measuring the marginal and internal fit at multiple planes and locations.[74,75] It can be used for quantitative analysis and for visualization by specifying cement thickness. In addition, it allows longitudinal assessment of the marginal and internal fit of the same sample before and after employing different testing variables. However, it has a difficulty measuring metallic frameworks and titanium copings due to metallic artifacts. Moreover, there is an increased risk of exposing the operator to radiation.[76]

Triple scan technique: It is a non-destructive and non-radioactive method that was introduced to overcome the shortcomings of the previous conventional 2D fit assessment approaches.[77] This protocol is an alternative internal 3D fit method that registers point clouds of three scans in surface tessellation/triangulation language (STL): the coping, the die and the coping on the die.[77] The last complex scan is used to reposition the die and coping surfaces where the best-fit algorithm minimizes the distance between the two scans. Then, the distance between the surface of the abutment and the intaglio surface of the restoration is calculated.[77,78]

The method provides reproducible results on manufacturing distortion and misfit. Since it is a non-destructive method, it allows for repeatable measurement of the same objects before and after cementation.[78] It is also useful in case of small sample size since it has no limit in the number of sections and measuring points it can provide in comparison to the other measuring methods. It provides a higher number of points that are distributed over the entire surface of the marginal and internal areas of the abutment's fitting surface.[79]

On the other hand, the need to spray shiny surfaces of the abutment and the framework with titanium dioxide to enhance contrast and facilitate scanning can be a source of error.[47] Besides the use of spray, Holst et al.[80] has sandblasted the outer and intaglio surfaces of the titanium copings using 35 μm aluminum oxide to reduce their reflectivity and facilitate their digitization. Moreover, miscalculations that produce negative values, implying that the restoration is smaller than the master die, may occur due to possible inaccuracy and overlapping of the scanned data.[81] The method is time-consuming and requires the use of a costly industrial scanner.[42]

Dual scan technique

This is another non-destructive and non-radioactive method. It is a digitized version of the replica technique and a 3D fit method that registers point clouds of two scans, one scan being of the prepared abutment and the other being taken of the abutment with a silicone layer that represents the cement space. The internal and marginal fit analysis can be done semi-qualitatively, in a colour-coded map, as well as quantitatively, in microns.

Dual-scan technique was introduced by Lee et al.[81] to overcome the miscalculation that may occur while superimposing the 3 digital scans in the triple-scan technique. It produces more accurate calculations since it superimposes 2 digital scans only, one of the scans is for a silicone impression of the actual cement space, to avoid any negative results that might occur due to the risk of over-superimposing the scans. In comparison to the conventional replica technique, where the information could be lost, digital data of cement space can be stored permanently in a 3D image. It can be sectioned in unlimited number in any direction on the CAD software. It simplifies the communication between a dentist and a dental laboratory technician, which eventually improves the prosthesis quality management. The cement space and the vertical and horizontal misfit around the margin of prostheses can be easily measured in daily practice by a clinician using a tool supported by most available CAD software.[81]

However, the fragility of the used light body PVS material indicated the application of different materials, such as adhesive or lubricant, to prevent the distortion of the silicone layer while removing the crown from the abutment. This thin layer of adhesive can introduce an error in the fit assessment.[81] Another source of error can be the use of lubricant on the intaglio surface of the crown before injecting a thin layer of the silicon material into the crown.[82,83] Similarly, surface conditioning using powder spray, which is at least 5µm thick, to prevent the light reflection of the optical scanner, can cause inaccurate measurement of the cement space.[81]

1.5.5 Factors Affecting Marginal Fit

A recent systematic review[63] of 41 studies determined the different variables affecting the marginal fit and internal accuracy of zirconia FPDs on natural teeth. They attributed the wide heterogeneity in the MD found in the included studies to the different used materials, CAD-CAM systems, experimental methodology, sample size, and span length of the tested FDP. They reported that CAD/CAM systems produce FDPs of more precise marginal and internal fit than traditional systems. In addition, they found that framework span length to 6 or more units decreased both marginal and internal fit; besides that, the reported marginal gap tended to increase after the veneering process. Moreover, they noted that the introduction of a conventional impression into a digital workflow seems to have a negative effect on the marginal fit. Another systematic review[79] included 183 studies to evaluate the marginal and internal fit of different all-ceramic systems by various methods. They found that direct view technique was used by 47.5 % of the articles, followed by cross-sectioning (23.5 %) and impression replica (20.2 %) techniques. Moreover, validating MG measurements among these methods generated great variation even within the same ceramic system. This was attributed to different experimental setups in the included studies. There is no conclusive evidence on the best methodology or standard protocol to evaluate the marginal adaptation of crowns and FDPs. Recently, Son et al.[79] prepared the upper right first molar in a dental model for a single coping designed with a cement space of 40 μm, milled of pre-sintered Y-TZP and had no internal or external adjustments after sintering. One sample only was used to minimize production errors. A guide template was used to measure the fit at 10 points at the same four regions for each analysis: marginal gap, axial gap, angle gap and occlusal gap on the four sides: buccal, palatal, mesial and distal. There were statistically significant differences in the marginal fit between the cross-sectional method (23.2 μm) and the silicon replica technique (33.5

μm), and between the triple scan method (74.1 μm) and the optical coherence tomography (83.4 μm). Similarity between the results of cross-sectional and replica techniques was attributed to a possible error in digitizing the samples in each method which could be decreased by developing better equipment and improving the used methods. Boitelle et al.[47,84] found that the median values of marginal fit of sixty zirconia copings were ranged between 43.35 μm to 68.4 μm with the replica method and 48 μm to 71.2 μm with the triple-scan technique. There were no internal adjustments made to the milled copings. However, greater data dispersion was found for the replica method (5.6%) in comparison to the triple scan technique, which had smaller measurement errors, low repeatability coefficient and a high intraclass correlation coefficient.[78] The considerable reliability of the triple scan technique can be due to using a higher number of measurement points (268 ±82) than that considered in replica method (8 measurement points and 5 measurements per specimen). It can also be attributed to the distribution of the measurement points. In the replica technique, the information is lost due to cutting the silicone replica and the selection of the points by the examiner, while in triple scan technique the points are selected over the entire surface of the marginal area without losing data. The selected method of acquiring the fitting surfaces to be evaluated, whether it is 2D or 3D, can also be a factor to consider. In addition, the silicone layer between the coping and the die in the replica technique can introduce measurement uncertainties based on its homogeneity, viscosity and how it was manipulated by the operator.

Another factor might affect the measured marginal and internal fit is the use of titanium dioxide spray to enhance the contrast and facilitate scanning of the die as well as the coping when using the triple scan protocol. This thin coat might cause errors by decreasing the cement space, especially that it is difficult to be handled clinically in a moist environment.[85] However, Holst et al.[84] and Matta et al.[41] have reported that this source of error is insignificant.

The evaluation of marginal and internal fit of multi-unit FDP should be done at the single retainers on the single abutments as well as the fit of all the retainers on all the abutments. This is noteworthy since a clinically acceptable fit at the single retainers does not mean that the whole FDP fits on the abutments, because one retainer might be prevented from fully seating by the other retainer misfit.[48] Therefor, a multi-unit FDP must have a clinically acceptable fit at both retainers simultaneously, besides that the cement space should be even at all the retainers when the restoration is seated.

Direct comparison of the values for MG between studies were not always possible due to the lack of consistency regarding the definition of "fit". Holmes et al.[84,86] proposed a clear terminology describing "fit" of dental restorations, as previously discussed. Some studies employed this terminology, with either MG or the absolute marginal discrepancy being the evaluated. Other studies, however, do not use the same definitions for the marginal discrepancies, hence, direct comparisons between studies are/were difficult.[47] Similarly, some studies have defined the marginal fit as the band 0.5-1.0 mm occlusal to the preparation margin while the rest space is the internal fit.[87,88] On the other hand, other studies have defined the marginal fit as the band 0.75 mm occlusal to the preparation margin.[89]

Additionally, studies varied in their experimental setups, sample size and number of measurements per specimen, method of fabrication (conventional vs. CAD/CAM), and when the gap was measured (before/after cementation).

1.5.5.1 Impact of Number of Measurements/ Sample Size

The required sample size of restorations required to evaluate the marginal and internal fit is controversial. Adequate sample size and number of measurements per one specimen are important to obtain strong statistical analysis and conclusion in a study.[65] Several studies based their results on 2 to 24 measurements per sample.[42] Another study noted that the common sample size ranges from 5 to 10 specimens per group, with 2 to 150 different measuring locations, selected in a systematic or random manner. Contrepois et al.[89] reported that the optimal number of measurement sites required to evaluate marginal fit ranges between 18 and 50 points, while Nawafleh et al.[42] pointed out that most authors have used 4 to 12 points. In this context, Groten et al.[89] suggested that a minimum of 50 measurement locations along the margin of a crown yielded clinically relevant information and a consistent estimate for gap size (i.e. within ±5 μm variability for arithmetic means). They concluded that at least 20 measurements per sample could be accepted based on the required precision level.[89] Gassino et. al.[64] claimed that Groten et. al.[89] results were flawed. Gassino et. al.[64] employed a more sophisticated methodology of running 360 gap measurements circumferentially at 360° and determined that 18 measurements were needed to assess experimental crowns that are fabricated from abutments prepared in the laboratory and 90 measurements for clinical crowns fabricated from abutments prepared intraorally to generate a sample mean within ±5 μm of the true mean, with 4 μm standard error. However, some conclusions in this study were based on the analysis of only 2 crowns, which might not be representative of everyday practice. Both studies had small sample size and compensated this with a large number of measurements per sample to achieve a more consistent distribution of data with small standard deviations. One of the advantages of triple scan technique in comparison to the other measuring methods is its ability to evaluate the marginal and internal fit at a cloud of points which would provide more precise results.[90] Although increasing the number of gap measurements per specimen enhances the precision of the analysis, the longer time required for recording the measurements and the complexity of the measurement method makes the approach impractical to perform on a regular basis. Toward this end, more studies involving 3D analysis of MG using dual-scan protocol could provide a more realistic perception of MG within the range of a few micrometers at multiple sites and directions. The resulting 3D data sets could be used for both quantitative analysis and for visualization by specifying cement thickness. Moreover, the volume and geometry of MGs can be assessed from 3D reconstructions.

1.5.5.2 Influence of method of fabrication

In the literature, a couple of studies showed how different manufacturing workflows, either conventional, conventional-digital, in-office CAD/CAM or lab CAD/CAM, would make a difference in the marginal and internal fit of the produced restorations. Mello et al.[91] compared the marginal fit and internal adaptation of 3-unit FDPs fabricated using different CAD/CAM systems, 10 FDPs in each group, where some FDPs were manufactured in house while others in-office for the CEREC 2 groups. Systems included iTero/industrial CAM, CEREC Bluecam/industrial CAM, CEREC Bluecam/Dentsply Sirona (chairside CAM) and 3S/industrial CAM. The vertical MD of the systems was 54.8 µm, 120 µm, 114 µm and 98.6 µm, respectively.

In a recent systematic review, Bousnaki et al.[46] found that CAD/CAM systems provide more precise marginal and internal fit than CAM only systems (where traditional wax pattern is made then digitized). Beuer et al.[90] has compared the marginal and internal fit of 3-unit FDPs designed and manufactured by two CAD/CAM systems, Etkon and CEREC inLab, to one CAM system, Cercon. Difference between the average MD of the 10 FDPs in each group was noted. The results showed the superiority of CAD/CAM over CAM in terms of fitting accuracy, where the frameworks from the CAD/CAM groups provided significantly better marginal fit (Etkon: 29.1 ±11.3 µm and CEREC inLab: 56.5 ±17.2 µm) than those form the CAM group (Cercon: 81.4 ±20.4 µm). Bindl and Mormann[87] found significantly better marginal fit of frameworks fabricated using CAD/CAM in comparison to those fabricated with CAM only system. Kohorst et al.[92] reported that lab CAD/CAM showed less MG in comparison to CAM only workflow.

1.5.5.3 Effect of sintering

There are two types of zirconia blanks: fully sintered blanks that require hard milling, and pre-sintered blanks that are soft milled. Sintering Y-TZP is a process of slow heating and cooling (5-10 °C/minute) and dwelling that takes hours. Since traditional sintering use 1350-1550 °C with 2-5 hours for dwelling, the restoration won't be delivered until the next appointment. Fast-sintering was developed and provided a choice of delivering restorations with good mechanical[93] and optical properties and wear characteristics[94] in one visit[95]. Kauling at al.[33] compared the marginal and internal adaptation of 3-unit zirconia FDPs fabricated by a full-chairside CAD/CAM sintered using fast-sintering (Speedfire, Dentsply Sirona) and conventional sintering (inFire HTC speed, Dentsply Sirona). The marginal and occlusal fit were better in the Speedfire group.

1.5.5.4 Effect of cementation

The cement space is the space located between the intaglio surface of a restoration and its corresponding abutment. The creation of cement space is more critical than designing the margin for an adequately fitting restoration.[96] Conventionally, it is done by applying die spacer at the whole crown but not the margin. In the digital CAD/CAM workflow, the spacer can be set on the CAD software.[54] Insufficient cement space would prevent the complete seating of the retainer on the abutment, thus affecting its internal and marginal fit.[97]

Marginal and internal fit measurement could differ before and after cementation of the restoration. In one of the studies where the marginal discrepancy of single full-coverage tooth-supported crowns made of different materials was examined before and after cementation using SEM, it was found that cementation increased the vertical marginal discrepancy in all test groups and ranged between 16.46 μm to 21.03 μm.[42]

1.6 Summary of the available literature and study rational

The long-term success of dental restorations depends, among other factors, on their marginal and internal adaptation.[36] A good marginal fit is required to avoid plaque accumulation and eventually caries[38] and endodontic and periodontal diseases[37]. It is also important to avoid margins discoloration[38,39] and dissolution of the cement[38]. There are numerous factors that play a role in the measured amount of discrepancy: the type of scanner[55], type of material[56], fabrication method[34], finish line preparation[57], measuring technique[35,55,56,58–60], application of powder before scanning and internal adjustments to the intaglio surface of the restoration[55]. Most of the referenced studies were done for ceramic restorations.

In the last decade, full-chairside workflow has become the treatment option for many restorative dentists for the several advantages it provides. With such workflow, it is possible to produce restorations in less than one hour and there is no need for temporization. It also minimizes human errors, the need to adjust or remake, and any cross contamination associated with multistage fabrication processes. Old patients who have difficulty attending multiple and long dental appointments would benefit from such workflow as well.[30]

There is no conclusive evidence on the best methodology to evaluate the marginal and internal adaptation of different tooth-supported restorations. Due to the use of different definitions for fit, direct comparison of MG of different studies is usually not possible. Moreover, this is attributed to the different methods used to evaluate the marginal and internal fit as well as the different experimental setup (in-vitro vs in-vivo), sample size, number of measurements per specimen, preparation, finish line design and time of measurement (before/after) cementation.

Marginal discrepancy was measured using different methods in different studies in the literature. The direct view and cross-sectional techniques are the most used in-vitro methods to measure MG. The direct technique has advantages of being non-destructive and cheap. However, projection error and difficulty identifying reference points for measurement and repeating measurements from an identical angle limit the direct viewing method. The cross-sectioning technique is a destructive method that allows for direct measurement of the internal gap and MG. However, it does not permit longitudinal assessment of the results before and after different manufacturing stages using the same specimens, and cannot be used to evaluate the crowns prior to clinical placement.[42] Micro-CT is another method that overcomes the previously mentioned limitations of the direct and cross-sectional methods. It can provide a more realistic 3D measurement of the marginal and internal fit at multiple sites and directions and can be used for quantitative analysis and visual colour coding. However, micro-CT cannot be used in case of zirconia restorations due to metallic artifact that would interfere with identifying and measuring marginal and internal gaps. Triple scan is a non-radioactive method. It integrates the scans by the best-fit alignment feature that finds the common areas between the different scans for matching and repositioning where the distance between the intaglio of the restoration and the abutment is measured.[78] However, it shows negative measurements due to the over-integration of the three digital scans. Therefore, dual-scan technique was developed to overcome this problem by scanning the actual cement thickness that is produced in form of elastomeric impression.

In the literature, the marginal and internal fit of dental restorations fabricated by a full-chairside CEREC CAD/CAM system have been tested for single-tooth crowns made of ceramic materials such as feldspathic ceramic (Vitablocs, Vita Mark II), leucite reinforced glass ceramic (Empress CAD), and lithium disilicate glass ceramic (e.max CAD, and Celtra Duo).[35,55,59,60,86] Yet, studies to test the marginal fit and internal adaptation of monolithic zirconia multi-unit FDPs fabricated using full-chairside CAD/CAM system are needed.

Therefore, the objective of this thesis was to compare the 3D marginal and internal gap of monolithic zirconia 3-unit FDPs fabricated with digital full-chairside (FCH) and lab (LAB) CAD/CAM workflows using dual-scan technique.

1.7 Specific aims

To determine, using dual-scan technique, the vertical MG and internal adaptation of 3- unit FDPs made of monolithic zirconia fabricated using:

- **Full-chairside digital workflow**: intraoral scan, chairside CAD/CAM and fast sintering.
- **Lab CAD/CAM digital workflow:** intraoral scan, inLab CAD/CAM and fast sintering.

1.8 Hypothesis

- The **null hypothesis (H0)** of this study was that there is no significant difference between CEREC chairside and lab CAD/CAM workflows based on digital 3D assessment of marginal and internal fit.

- The **alternative hypothesis (H1)** of this study was that there is significant difference between CEREC chairside and lab CAD/CAM workflows based on digital 3D assessment of marginal and internal fit.

Chapter 2: Methods and materials

2.1 Sample size calculation

Power analysis, based on our pilot study, indicated that a sample size of 12 was required to detect significant mean differences of 35 μm between the groups in the presence of 30 μm standard deviation. In this power analysis, α was set to 0.05 and β was set to 0.20, to allow for 80 % power.

2.2 Preparation of the abutments

The maxillary right first bicuspid (tooth #14) and the maxillary right first molar (tooth #16) (FDI World Dental Federation notation) were prepared for 3-unit monolithic zirconia FDP on an ivorine typodont (Frasaco, N.C., USA). Both abutments were prepared following the manufacturer recommendations for Katana STML (Kuraray Noritake Dental, Japan) with circumferential 1.0 mm chamfer finish line, functional cusp, and non-functional cusp reduction. Teeth #14 and #16 were selected because they were considered more suitable for assessing margin fit as they have more complex preparations than anterior teeth.

2.3 Accuracy of digital scanning

The accuracy of digital scanning using Primescan was tested by finding the trueness and precision. One calibrated examiner did ten IOS for the abutment teeth to ensure consistency of the repeated IOS for the abutment teeth. Precision describes how close repeated measurements are to each other. The higher the precision, the more predictable measurements. Trueness is a linear distance measurement of the closeness between the test object and the reference object. The higher the trueness, the closer the result to the actual dimensions of the measured object. According to Ender et al.[98] A higher precision was found when scanning the posterior segment of the arch using CEREC primescan scanner in comparison to scanning the anterior segment or the complete arch. Therefore, scanning the first quadrant of the maxillary typodont model where the prepared abutments #14 and #16 was considered for this study.

To determine the trueness of CEREC Primescan scanner, ten half-arch scans were taken using the manufacturer recommended a scanning pattern starting from the lingual surfaces, the occlusal, then the buccal (Figure 1). The first scan was considered as the control scan to superimpose each of the other 9 scans over. The respective area was evaluated using 3D superimposition method with special 3D difference analysis software Control x v2020.0 (Geomagic, GmbH, Stuttgart, Germany) starting with initial alignment of the scans to the control scan, then best-fit algorithm for accurate superimposition (Figure 2).

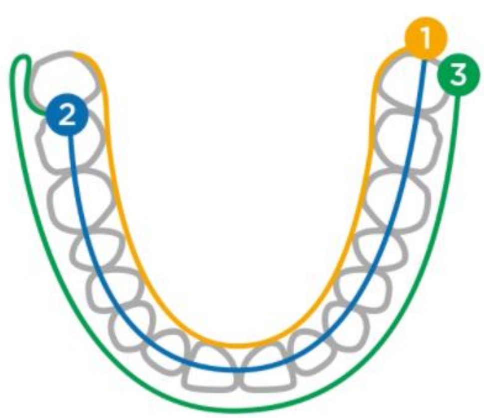

Figure 1. The recommended scanning pattern of Primescan IOS (CEREC, Dentsply sirona)

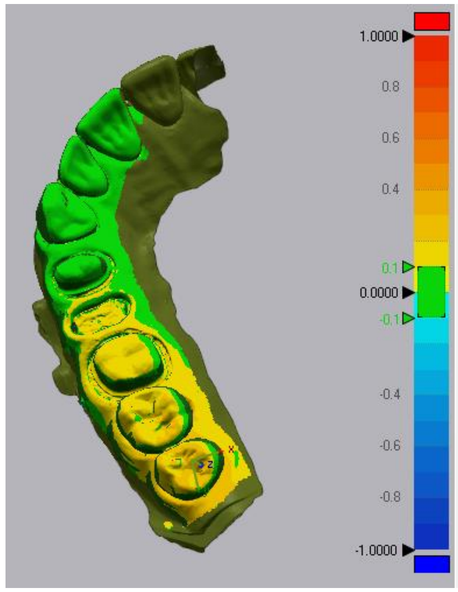

Figure 2. 3D evaluation of the half- arch scans for intra-reliability test

2.4 Monolithic zirconia 3-unit FDP fabrication

The maxillary typodont was digitized fifteen times, using CEREC Primescan IOS (Dentsply Sirona, Germany), and used in the fabrication of FCH 15 STML MZ 3-unit FDPs (Figure 3). The same 15 scans were exported (in dxd) and sent to the dental lab to fabricate 15 LAB STML MZ 3-unit FDs.

To ensure consistency in designing different FDPs in the study, a Poly (Methyl Methacrylate) (PMMA) 3-unit FDP was designed according to the manufacturer recommendation for Katana STML of having 16 mm^2 connectors size and used as a biocopy to CAD design all FDPs in the FCH and LAB groups (Figure 3). FCH FDPs were designed using CEREC CAD software v 4.5.1 (Dentsply Sirona, Germany), dry milled with CEREC MC X (Dentsply Sirona, Germany) and fast sintered using Speedfire (Dentsply Sirona, Germany) (Figure 4). LAB FDPs were designed using Exocad (Exocad GmbH, Darmstadt, Germany), milled using Zirkonzhan 600/V3

(Zirkonzahn, South Tyrol, Austria) and fast sintered. The same CAD parameters (Table 2) and sintering settings (Table 3) were used in the fabrication of FCH and LAB groups. No adjustments were made to the intaglio surfaces of the fabricated FDPs.

Figure 3. FDP preparation and design using CEREC technology: A. Typodont with teeth #14 and 16 preparations for monolithic zirconia 3-unit FDP, B. Scanned preparations, C. Biocopy, D. Outlining the biocopy, E. Biogeneric proposal according to the biocopy, F. Edited occlusal and proximal contacts, and G. Milling screen.

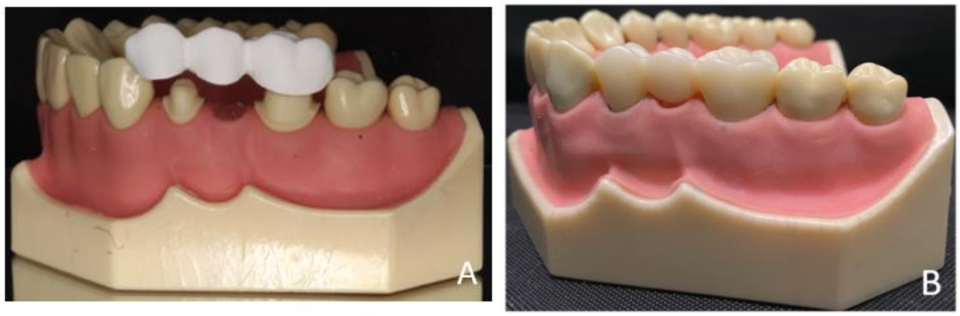

Figure 4. The difference in the size of the monolithic zirconia before and after fast-sintering: A. Milled monolithic zirconia 3-unit FDP before fast-sintering. B. 25% shrinkage of the monolithic zirconia 3-unit FDP after fast-sintering.

Table 2. CAD parameters (µm) for monolithic zirconia 3-unit FDP.

Radial spacer	**80**
Occlusal spacer	**120**
Radial minimal thickness	**800**
Occlusal minimal thickness	**1500**
Proximal contact strength	**25**
Occlusal contact strength	**-50**
Dynamic contact strength	**-75**
Margin thickness	**50**
Margin ramp width	**0**
Margin ramp angle	**45°**

Table 3. Fast-sintering program settings for Katana STML (Kuraray Noritake Dental, Japan)

High temperature	**1560 °C / 2840 °F**
Hold time	**30 minutes**
Rate of temperature increase	**35 °C / 95 °F /minute**
Rate of temperature decrease	**-45 °C / -49 °F /minute**

2.5 Dual-scan technique

The marginal and internal adaptation of each MZ 3-unit FDP were recorded using extra light-body PVS (Aquasil Ultra LV, Dentsply Sirona, Germany) impression. The intaglio surface of each FDP was lightly wiped with a lubricant (Vaseline) and air distributed before taking the PVS impression of the cement space. The retainers of the FDP were seated on the corresponding abutments with finger pressure for 10 minutes for the impression to set. After setting, the excess PVS material was removed from the margins and the FDP was removed carefully with a pulling motion at the mesial and distal connectors using crown removal forceps, leaving a layer of the PVS impression material on the surfaces of the prepared abutments. The excess of PVS material was trimmed with a scalpel after the finish line of the preparation. A half-arch scan where the PVS layer on the abutments was taken using CEREC Primescan IOS (Dentsply Sirona, Germany). The same procedure was done for all of the thirty MZ 3-unit FDPs. This scan represents a replica of the cement thickness representing the axial and occlusal internal adaptation as well as the marginal fit of the retainers of the produced MZ 3-unit FDPs (Figure 5).

Standard Tessellation Language (STL) files of the scan of the abutments and the scan of the PVS layer were exported from the scanner. Both STL files were imported into Control x v2020.0 (Geomagic, GmbH, Stuttgart, Germany) and superimposed using 3D superimposition method to find the dimensional differences between both groups. The superimposition was done in two stages: first, the two STL files were initially aligned, then superimposed using the best-fit algorithm (Figure 6: A, B, C & D).

Figure 5. Dual-scan technique: A. Prepared abutment teeth which were scanned and used for dual-scan technique: A. Digital scan of the abutments. B. Light-body PVS impression of the monolithic zirconia 3-unit FDP. B. PVS layer thickness representing the cement space which was scanned and used for dual-scan technique.

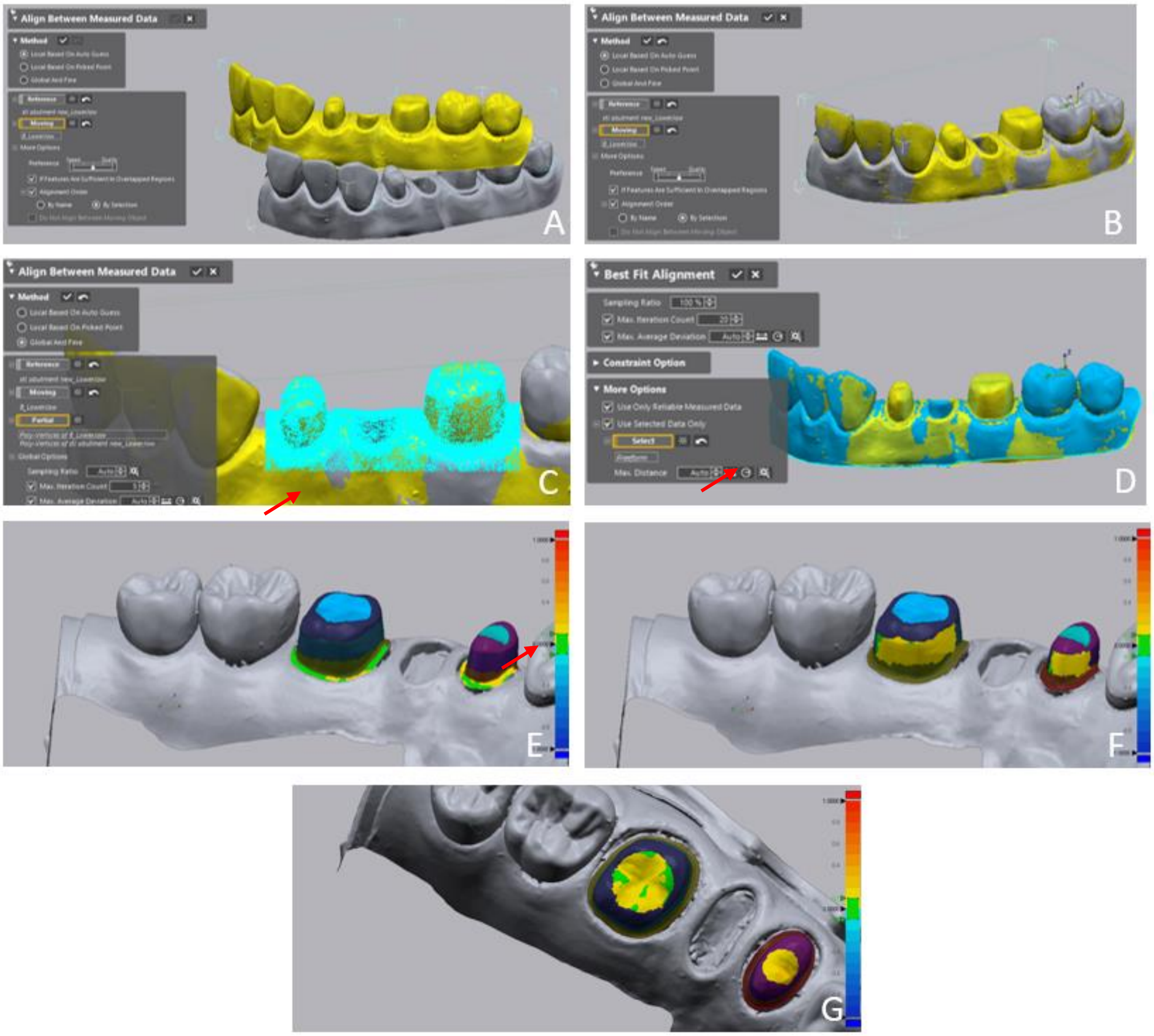

Figure 6. 3D evaluation of the marginal and internal adaptation of monolithic zirconia 3-unit FDP: A. Two digital scans (STL) files; one of the abutments and another of the PVS impression layer on the abutments. B & C. Initial alignment of the two scans. D. Best-fit alignment. E. 3D evaluation of the marginal fit (arrow). F. 3D evaluation of the internal adaptation at the midaxial band circumferentially (arrow). G. 3D evaluation of the internal adaptation at the circular occlusal region (arrow).

2.6 Marginal and Internal adaptation Measurement

The distances between the different points of both data sets of the prepared abutments and the PVS layer were calculated using the 3D compare tool to show the results in a colour coded map. Around 20,000 point per surface matching were selected. Using the insert region tool, three regions were selected to assess the marginal and internal adaptation of the FDP: marginal (MA), axial (AX) and occlusal (OC) (Figure 6: E, F & G). MA region was selected 0.5 mm from the preparation margin line because of the difficulty to determine the exact preparation margin line due to the inability to cut the mesh triangles of the STL file. AX region is a 2 mm mid-axial circumferential band. OC region is a 4 mm and 8 mm diameter circular area in the mid of the occlusal surface for the abutment #14 and #16 respectively.

To validate the digital measurements of the used dual scan technique, the thickness of the occlusal surfaces of the PVS replica of five randomly selected FDPs were measured using a calibrated micrometer caliper with a measurement error of ±5-10 µm (Figure 7).

Figure 7. A calibrated micrometer caliper used to measure the PVS thickness to validate the digital measurements.

2.7 Statistical analysis

The Kolmogorov-Smirnoff test was used to test for normal distribution of the data. The mean, median, standard deviation (SD) and 95 % confidence interval (CI) were calculated for each group using descriptive statistics. Homogeneity of variance was tested using the Levene test. The statistical analysis was performed using uni-variate ANOVA to compare the difference in the MG, AX and OC in MZ 3-unit FDPs fabricated by two workflows: FCH and LAB CAD/CAM. Post-hoc Scheffè test ($p=0.05$) was used to detect any significant differences in terms of the fit for the single measurement areas of the complete FPD and the single measurement areas between the abutment teeth. The descriptive statistic values of trueness and precision were given as median with interquartile range (IQR) (all values in mm). A statistical software program IBM SPSS Statistics 27 (IBM Corp, Chicago, IL, USA) was used for the analysis.

Chapter 3: Results

3.1 Accuracy of digital scanning

Precision of the half-arch digital scans of the prepared teeth using CEREC Primescan scanner was interpreted as mean ± SD in micrometers 21.4 ±94.3 μm. Trueness of the half-arch digital scans of the prepared teeth using CEREC Primescan scanner as interpreted in median [IQR] and mean ± SD in micrometers, 13.1 [44.3] μm and 21.21 ±23.5 μm respectively.

3.2 Marginal and Internal Gap Measurements

3D colour-coded scheme was used was used to assess internal and marginal fit for each FDP at three different areas: MA, AX and OC (Figure 6: E, F & G). The measurements were tested for normal distribution using the equality of variance (Figure 8). An overview results of the fitting accuracy for the MZ 3-unit FDP (at both retainers 14 & 16) and at each individual retainer for both CAD/CAM systems (FCH and LAB) is shown in Table 4. According to the quantitative analysis, all the measurements were clinically acceptable. There was no statistically significant difference between the marginal and internal fit of the FDPs fabricated using FCH and LAB (Figure 9). In group FCH, the measured fit of the FDP at both retainers 14 and 16 at the MA is 77.50 ±29.99 μm, at the AX is 99.67 ±21.58 μm and at the OC is 150 ±30.78 μm. On the other hand, the fit of the LAB FDPs at 14 and 16 at MA is 100.27 ±27.06 μm, at the AX is 116.53 ±17.94 μm and at the OC is 142.30 ±19.95 μm. The fit at retainer 14 in the FCH FDPs is as follows: Ma (87.60 ±30.69 μm), AX (104.80 ±25.84 μm) and OC (158.53 ±25.08 μm). The fit at retainer 14 in the LAB group is: MA (105 ±23.19 μm), AX (117.60 ±20.48 μm) and OC (146.53 ±19.27 μm). The fit at retainer 16 in the FCH FDPs is: MA (67.40 ± 26.50 μm), AX (94.53

±15.51 µm) and OC (141.53 ±34.34 µm). The fit at retainer 16 in the LAB FDPs is: MA (95.53 ± 30.51 µm), AX (115.47 ± 15.66 µm) and OC (138.07 ± 20.36 µm).

Levene test showed general homogenous variance between the groups (p=.018). Uni-variate ANOVA and Post-hoc Scheffè test showed no statistically significant differences between the FCH and LAB CAD/CAM workflows, abutment teeth #14 & #16 and areas (MA, AX and OC) (Table 4).

The outcome of conventional replica measurements of five randomly selected FDPs using a calibrated micrometer caliper were similar to the digital measurements using the dual-scan technique with a measurement error of ±5-10 µm (Table 5).

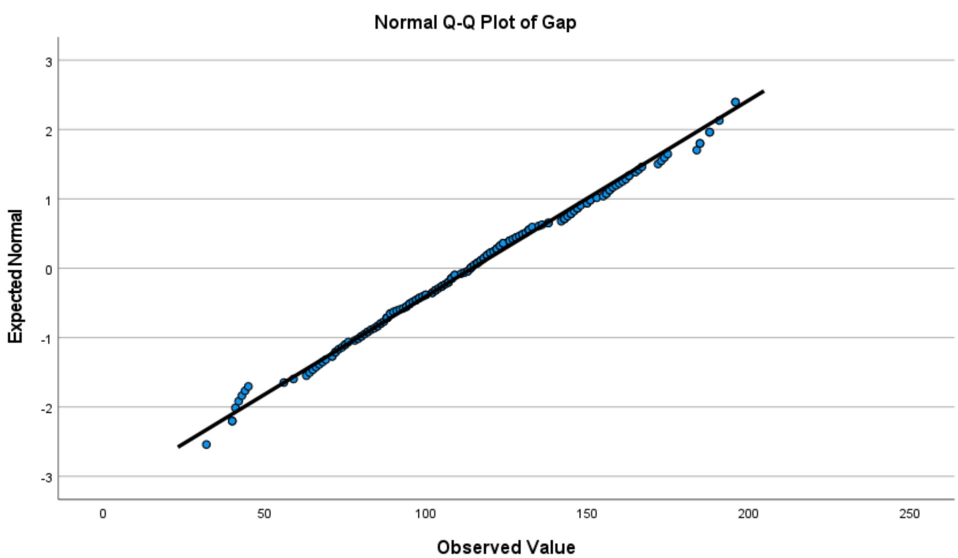

Figure 8. Q-Q Plot shows normal distribution of the data

Table 4. Results for fitting accuracy of monolithic zirconia 3-unit FDPs fabricated using full-chairside and lab workflows.

	Full-chairside CAD/CAM			Lab CAD/CAM		
Measurement Area	**FDP (µm)**	**#14 (µm)**	**#16 (µm)**	**FDP (µm)**	**#14 (µm)**	**#16 (µm)**
Marginal						
Mean ± SD	**77.50± 29.99**	**87.60 ± 30.69**	**67.40 ± 26.50**	**100.27 ± 27.06**	**105.00 ± 23.19**	**95.53 ± 30.51**
Minimum	**32.00**	**40.00**	**32.00**	**64.00**	**64.00**	**66.00**
Median	**75.00**	**87.00**	**73.00**	**94.50**	**98.00**	**82.00**
Maximum	**158.00**	**158.00**	**116.00**	**156.00**	**147.00**	**156.00**
95% CI	**66.30-88.70**	**70.60-104.60**	**52.73-82.07**	**90.16-110.37**	**92.16-117.84**	**78.64-112.43**
Axial						
Mean ± SD	**99.67 ± 21.58**	**104.80 ± 25.84**	**94.53 ± 15.51**	**116.53 ± 17.94**	**117.60 ± 20.48**	**115.47 ± 15.66**
Minimum	**59.00**	**59.00**	**71.00**	**80.00**	**80.00**	**86.00**
Median	**96.00**	**105.00**	**91.00**	**116.50**	**114.00**	**119.00**
Maximum	**151.00**	**151.00**	**122.00**	**150.00**	**150.00**	**145.00**
95% CI	**91.61-107.73**	**90.49-119.11**	**85.94-103.12**	**109.83-123.23**	**106.26-128.94**	**106.80-124.14**
Occlusal						
Mean ± SD	**150.03 ± 30.78**	**158.53 ± 25.08**	**141.53 ± 34.34**	**142.30 ± 19.95**	**146.53 ±19.27**	**138.07 ± 20.36**
Minimum	**103.00**	**103.00**	**103.00**	**104.00**	**124.00**	**104.00**
Median	**153.001**	**163.00**	**126.00**	**140.50**	**143.002**	**132.00**
Maximum	**196.00**	**196.00**	**196.00**	**185.00**	**185.00**	**173.00**
95% CI	**138.54-161.53**	**144.64-172.42**	**122.52-160.55**	**134.85-149.75**	**135.86-157.21**	**126.80-149.34**

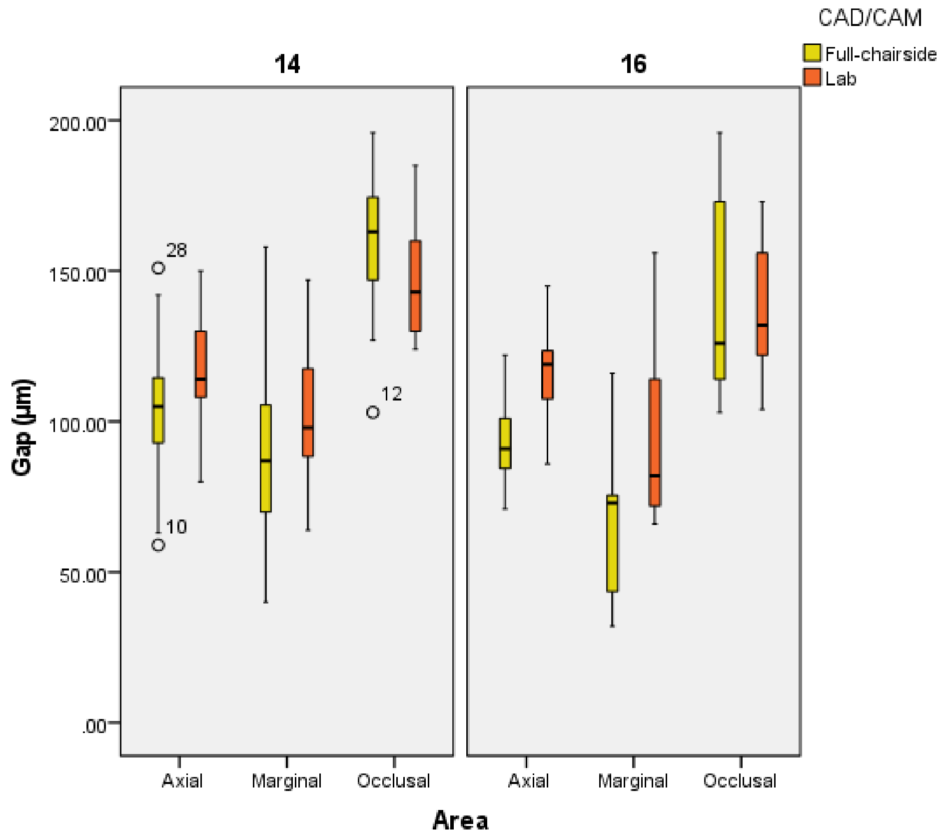

Figure 9. Boxplot for the fit of the 3-unit monolithic zirconia FDPs fabricated by Full-Chairside CAD/CAM workflow and Lab-based CAD/CAM workflow at 14 & 16 retainers. The fit evaluation was performed at 3 areas of each abutment: axial, marginal and occlusal. ° indicate outliers.

Table 5. Comparison of the digital replica and conventional replica at 3 different surfaces (Occlusal, Palatal and Buccal).

	Surface	Ave. (μm)	SD. (μm)
Digital replica	Occlusal	188.1	29.2
	Palatal	46.0	19.8
	Buccal	55.6	14.0
Conventional replica	Occlusal	182.4	-
	Palatal	49.1	-
	Buccal	50.3	-

Chapter 4: Discussion

Full-chairside CAD/CAM has proven its efficiency in fabricating partial and full-coverage single unit restorations in the same visit without the need for provisional restoration. Such workflow is tremendously useful for patients who cannot attend multiple appointments to get the restoration done, such as elderly people. Monolithic zirconia was recently integrated in the full-chairside CAD/CAM. Due to the higher mechanical properties of zirconia material, the use of monolithic LS_2 in posterior multiunit FDPs was replaced by layered zirconia. [8–11] The problem of veneer chipping and fracture of layered zirconia was solved by using monolithic zirconia. The high opacity of this strong material was one of its disadvantages which then was resolved by using the new multi-layered zirconia that is more translucent and esthetic.[20,21] There is limited evidence to prove the efficiency of FCH fabrication of monolithic zirconia FDPs.[33,91] Therefore, the aim of this study was to evaluate the marginal fit and internal adaptation of 3-uni FDPs fabricated by two different CAD/CAM workflows: full-chairside and lab, where a new CEREC Primescan intraoral scanner was used, and new esthetic monolithic zirconia material (Katana STML). Every effort was taken to standardize the CAD/CAM and sintering of the fabricated FDPs in both groups: FCH and LAB. The intraoral scanner was calibrated before taking the IOSs. The same half-arch IOSs were used for both groups. A biocopy was used in the CAD of all the FDPs to ensure consistency of the design used in both groups. The same CAD parameters were considered in both groups. A new set of milling burs were used in the CAM of every 5 FDPs of both groups to avoid the use of non-cutting dull burs and to ensure the production of same quality restorations. The same recommended sintering protocol by the manufacturer was followed in both FCH and LAB groups.

Two abutment teeth, #14 & #16, were prepared and scanned to fabricate 3-unit monolithic zirconia FDPs using FCH (n=15) and LAB (n=15) workflow. The scanner used in both workflows was CEREC Primescan, the used CAD software and CAM machines were different. However, to minimize any variations, both groups used the same biocopy design for CAD/CAM parameters. Sintering protocols according to the manufacturer instructions.

The accuracy of CEREC Primescan intraoral scanner in terms of trueness is 13.1 [44.3] µm (median [IQR]), and 21.21 ±23.5 µm (mean ± SD), and precision is 21.4 ±94.3 µm (mean ± SD). These values are similar to what was reported in the literature. Diker and Tak[99] found that the trueness and precision (in median [IQR]) of the digital scans of right maxillary prepared teeth for 4-unit FDP using CEREC Primescan are 23[8] µm and 43[3.4] µm (in median [IQR]) respectively. This difference could be attributed to the longer edentulous area in the scan of 4-unit FDP from abutment 13 to 16[99] versus 3-unit FDP in this study. Moreover, Ender et al.[98] found that trueness was 21.9 [1.5] µm and 22.2 ±1.1 µm, and precision was 12.3 [2.6] µm and 12.9 ±2.2 µm when scanning posterior segment of the quadrant from tooth 13 to 17. In their study the scan was of teeth from 13 to 17, while in this study it was longer from 11 to 18 including an edentulous span at missing tooth 15.

Although crowns fabricated using FCH CAD/CAM do not require significant adjustments to improve their fit before cementation[49–51], FCH CAD/CAM multi-unit FDPs do. Both the fit of the complete FDP over the two abutments simultaneously and the fit of the individual retainer on each abutment should be considered. A clinically acceptable fit at one abutment does not mean that the whole FDP fits well since there is a possibility of misfit at one of the retainers.

According to Mclean et al, a clinically acceptable marginal gap is 120 µm[44]. Moreover, a recent systematic review studying the different variables affecting multi-unit zirconia FDP has shown that the required internal occlusal space for cement is around 80 µm[42] to provide a cushion effect for the brittle zirconia restoration. MZ 3-unit FDPs fabricated by FCH and LAB CAD/CAM workflows fit measurements are consistent with other studies.[33,91] In Kauling et al.[33] study, the fit at the same areas, MA, AX and OC were: 84.94 ±88.12 µm, 109.78 ±57.35 µm and 195.44 ±128.98 µm respectively which is comparable to the results of this study: MA (77.50 ±29.99 µm), AX (99.67 ±21.58 µm) and OC (150.03 ±30.78 µm). Mello et al.[91] found a higher MA discrepancy of around 114 µm.

In this study, both CAD/CAM groups, the internal and marginal fit measurements were different from the initial design parameters, especially the occlusal cement space. This can be attributed to the additional occlusal space integrated by CEREC. In addition, non-adjusted multi-unit FDPs expect less marginal and internal adaptation because of its rocking. They were not adjusted in this study to not introduce measurement errors. However, another study is needed to test the marginal and internal fit of these fabricated FDPs after adjusting the high points in its intaglio surfaces. Moreover, precision of the milling machine and burs, the mechanical properties of the material and abutment's geometry. It is also important to mention that pre-sintered zirconia blocks were used in this study that were sintered using fast-sintering protocol. Studies have shown that pre-sintered zirconia blocks experience 20-30% of shrinkage following sintering[100], this is more evident in fast-sintering than conventional sintering.[33] Therefore, the resulted smaller gaps than the entered design parameters can be attributed to this factor. Such restorations can be adjusted from their intaglio surfaces to improve their fit over the prepared abutments.

The null hypothesis that there is no statistically significant difference between CEREC chairside and lab CAD/CAM workflows based on digital 3D assessment of marginal and internal fit was accepted. There was no statistically significant difference in the fit measurements at abutment teeth #14 & #16 and areas: MA, AX and OC between FCH and LAB groups. Thus, it proved the efficiency of full-chairside CAD/CAM of monolithic zirconia 3-unit FDP in a single visit, especially for those patients who cannot attend multiple appointments to receive the final restoration.

The marginal fit and internal adaptation of the different restorations are commonly measured by 2D techniques such as the cross-sectional and the silicon replica techniques that requires point to point measurements on one plane or section. large number of cross-sections need to be combined to represent one area, but yet the required number of planes to accurately measure the fit is not known. It cannot evaluate the overall fit of the restoration circumferentially since the sections limit the number of measurements and can only be done in one direction.[64,65] Non-destructive 3D triple-scan technique overcomes this problem by measuring the fit in a selected area rather than a plane. The technique was considered in the beginning of this study. However, miscalculations and negative values were found due to inaccurate superimposition of the digital scans and this was also reported in previous studies.[81] Therefore, dual-scan protocol was utilized in the current study. It is another non-destructive digital measurement method and its measurements were validated by measuring the PVS impression thickness manually at the selected areas using a manual caliper following the protocol proposed by other studies.[33,81,101,102]

Strengths and limitations of the study

There are two studies that tested the fit of FCH 3-unit zirconia FDPs [33,91], but this study is the first to test the latest CEREC scanner (Primescan) and full-chairside CAD/CAM. Moreover, there was no powdering of the typodont abutments, while in Kauling et al.[33] study, the metal models could not be scanned without powdering which might introduce errors in the fit measurements. The IOS of the abutments had to be transmitted to another software to be able to export it in STL format to be used for the analysis, while the STL files were exported directly from the scanner in this study. This multiple transfer of the IOS data from one software to another could introduce errors in the measurements. While the other studies used the conventional replica technique [33] and the 3D optical microscope [91] to measure the marginal gap and internal fit of the FDPs, this study used the dual-scan technique that enables unlimited number of digital cross-sections of the scanned PVS layer over the abutments and it validated by conventional replica measurements using calibrated digital caliper. It also provides digital colour coded maps that measures the fit in an area instead of a cross-section which provides an overall fit assessment. It was also considered over the triple-scan technique to avoid any miscalculations and negative results due to over-integration of the scans. Moreover, digital data of the fit assessment can be saved in a form of 3D images. Besides, it is easy to be used clinically to assess the quality of the fabricated restorations.

One of the limitations of this study is the application of a thin layer of lubricant material on the intaglio surfaces of the FDP’s retainers. It was used to facilitate the removal of the FDP while taking the PVS impression without distorting the fragile PVS replica of the cement space.

However, it might introduce errors.[81] To eliminate the effect of the lubricant layer on the fit assessment, the layer was air distributed all over the fitting surface of the FDP to avoid any fit assessment errors. Finger pressure was used to seat FDPs while taking the PVS replica impression and was not controlled using a clamp or any sort of instrument.[101]

Chapter 5

5.1 Summary and conclusion

This study compared the marginal and internal fit of esthetic monolithic zirconia FDPs fabricated using FCH and LAB CAD/CAM workflows. The marginal and internal fit of the FCH and LAB FDPs are within the clinically acceptable range. Based on the outcomes of this study, the null hypothesis was accepted and the alternative hypothesis was rejected. There is no significant difference between CEREC chairside and lab CAD/CAM workflows based on digital 3D assessment of marginal and internal fit. Therefore, full-chairside fabrication of monolithic zirconia 3-unit FDPs can be considered as an efficient CAD/CAM workflow that eliminate temporization and delivers same day restorations with clinically acceptable marginal and internal fit that is comparable to lab CAD/CAM fabricated FDPs.

5.2 Future directions

Future studies are required to evaluate the marginal and internal fit after internal adjustments of the interfering high spots of the retainers. The dual-scan technique is still recommended because of the advantages it has over the other techniques as mentioned earlier. The efficiency of full-chairside CAD/CAM workflow has to be tested clinically by measuring the time required for IOS, CAD and CAM, in addition to the cost of the treatment in comparison to the lab CAD/CAM workflow. Moreover, the clinical performance of the new CAD/CAM biomaterials such as the esthetic multi-layered monolithic zirconia. The short and long-term biological complications (e.g. periodontal disease, caries and loss of vitality), mechanical complications (marginal gap, chipping and loss of retention), and success and survival rates of CAD/CAM multiunit FDPs need to be assessed in a clinical setting.

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