A unique method for evaluating marginal adaptation & internal fit of digitally designed lithium disilicate crowns manufactured by CAD/CAM and the conventional heat-press technique

I. INTRODUCTION: BACKGROUND & PROBLEM

Lithium disilicate has gained wide acceptance in its use for indirect crown restorations. This trend is driven by numerous factors ranging from the materials' excellent optical properties, flexural strength, and relatively decreased material costs when compared to high noble alloys. Lithium disilicate restorations have become a popular choice for inlays, onlays and full coverage crown restorations.

Computer-aided design and computer-aided manufacturing (CAD/CAM) processes are available in many dental practices, dental laboratories, and production centers.[1] Currently, there are more than eight companies that offer intra-oral imaging, with CEREC (Sirona), E4D (D4D Technologies), LAVA COS (3M), and iTero (Cadent/Align) being the most widely recognized and used. However, few have in-office milling options. For Laboratory CAD-CAM milling, Kavo, Dentsply, Sirona and Ivoclar are popular companies. The PrograMill Series of milling machines by Ivoclar was released in March of 2017. There are 3 models depending on the purpose, with the PrograMill 7 being the most advanced. It is a 5-axis operation design that has a dry and wet drilling mode, enabling a wide array of dental materials to be milled. The conventional wet drilling is used for IPS e.max©, Titanium, and Cr-CO alloys. The dry milling feature enables the use of acrylic resin, polyurethane, and wax. In the manufacture of indirect restorations, fabricating the wax pattern is usually a time consuming step which relies on the experience, knowledge, and skill of the dental technician. Thermal sensitivity, elastic memory, and a high coefficient of thermal expansion of waxes[2] contribute to inaccuracies. Fabricating CAD-CAM wax patterns with modern equipment can reduce or eliminate the inaccuracies of the conventional waxing technique.[3,4] It is said to be faster, more economical, predictable, consistent, and accurate. Ivoclar's ProArt CAD Wax discs are made from a dimensionally stable polyurethane material which are specifically designed to suit the lithium disilicate glass ceramic IPS e.max© Press. The material burns without leaving a residue.

It is thought that 40% of Dental Laboratories in the USA have milling units and although CAD/CAM technology has improved significantly, studies reveal that the accuracy of these restorations remains questionable. Controversies still exist on the effect of a milling procedure for a prosthesis. When comparing CAD-CAM restorations to pressed restorations, results vary from a better fit,[5,6] to no difference,[7,8] to a greater misfit.[9, 10, 11, 12, 13, 14] Accuracy is affected by many factors including the type of material, properties of the material, design of the preparation, scanning device, software design, spacer thickness, and accuracy of the milling machine.

Crown adaptation may be determined by measuring marginal gaps and internal gaps of the restorations. The fit of many full coverage restorative materials have been extensively studied in the dental literature and remains a topic of significant interest due to its high clinical relevance. Holmes et al characterized the internal gap as the perpendicular distance from the internal surface of the restoration to the axial wall of the preparation, whereas the marginal gap is the perpendicular distance from the internal surface of the restoration to the finish line of the preparation.[15] Holmes also stated that the marginal fit of any dental restoration is vital to its long-term success.[16] Schwartz et al evaluated unserviceable crowns and fixed partial dentures to determine causes of restoration failures and determined that 11.3% restorations failing are the result of defective margins.[17]

Behrend claims a ring of cement is inevitable at the margin and the presence of this cement line must be accepted, contributing to marginal discrepancies.[18]

A range of 39 to 180 μm[19, 20, 21, 22] has been proposed in the literature as a clinically acceptable value for marginal gap depending on the restoration. However, no consensus has been reached regarding a currently acceptable value for all. Several in vitro studies have reported the marginal gap of CAD/CAM generated ceramic single tooth restorations to be between 64 and 83 μm.[23, 24, 25, 26] May et al reported that the marginal fit of the Procera CAD/CAM system ranged between 54 and 64 μm.[27]

Many studies have been used to evaluate the marginal and internal adaptation of crowns. Assif et al compared the tactile method (with the explorer) to the use of radiographs and to a technique using impression material.[28] The results supported that the impression technique was most accurate of the three. The replica technique has been validated in the past.[29] The impression technique is a popular method,[30, 31, 32, 33] however, difficult and possibly inaccurate since the impression material used could be easily distorted or damaged.[34, 35, 36] Scanning electron microscopy is a popular technique in the analysis of pre-sectioned specimens.[37, 38, 39, 40] However, the obvious limitations of this technique are the destruction of the samples which creates the need for duplicates, the limited area that is evaluated since the sections have a minimum thickness and the additional steps required to embed in the resin and section. Another powerful tool in dental research is the computerized x-ray micro-tomography (micro-CT),[41,42] which produces high-resolution images that can be quantitatively analyzed with appropriate software. The disadvantages of this method are the low capacity the CT can discriminate in comparison with optical or electron microscopy, possible artefacts from refractive radiation, and the compulsory radio-opacity of the material being tested.

A significant drawback of the majority of published studies is the limitation of two dimensional analyses. With the advancement of technology, recent use of sophisticated professional engineering software have been gaining popularity.[43,44,45,46] It is based on non contact scanners and other hardware to capture point data, which are processed by algorithms in the software to process this data into useful forms. Thousands of point cloud data are converted in to a polygonal mesh as a 3D surface representation which are subsequently analyzed. However, best-fit registration algorithms are used for virtual alignment. The principle of this technique is adopted from industrial quality control protocols, where the software attempts to align the greatest possible contact area of the selected samples, which could skew the results, as areas of greater misfit are virtually approximated and not accurately represent the true discrepancy. Holst et al. developed a triple-scan protocol using a non-contact scanner (ATOS II SO, GOM mbH, Germany) for 3D fit assessment of dental restorations.[47] The sensitivity of the scanner is 3 microns. Three scans were performed and the objects were digitized to surface tessellation/triangulation language (STL's). Surfaces were generated from point clouds with the scanner software (ATOS system, GOM). Through a combination of best-fit algorithms and a subtractive method in the software, the fit assessment was verified by intra-class correlation coefficients that revealed an almost perfect coefficient for repeatability ($r=0.981$, $p<.001$). The same main investigator used this protocol in another study to assess the precision of fit of CAD/CAM dental implant superstructures.[48] The statistical analysis, again similar to the previous study, resulted in an intra-class correlation of 0.991 and thereby a statistically significant repeatability of measurements.

This triple-scan protocol represents a highly reliable method for analyzing marginal adaptation and internal fit three dimensionally. The disadvantages of 2D measurements are eliminated. This platform delivers the power to streamline the process, allow a non-destructive approach, reduce human interaction in measurements and recording, decrease measuring time, and enhance results to make this method a superior alternative.

II. OBJECTIVES & HYPOTHESES

Currently, there are no publications on the accuracy of Ivoclar's PrograMill 7 milling machine. The objective of this study is to evaluate marginal adaptation & internal fit of the digitally designed lithium disilicate crowns manufactured by CAD/CAM and the conventional heat-press technique with Ivoclar's PrograMill 7 milling machine using the triple-scan protocol. The null hypothesis is that CAD/CAM fabrication does not improve internal adaptation and marginal accuracy when compared with the conventional heat pressed technique.

III. RESEARCH DESIGN & METHOD

A master die will be fabricated to simulate a mandibular molar with an all-ceramic crown preparation. This master die will be scanned using a D1000 3-Shape scanner. Using 3-Shape software, a full-coverage crown will be designed per the manufacturer's (Ivoclar) minimum dimensional specifications. This design will serve two purposes:

A unique method for evaluating marginal adaptation & internal fit of digitally designed lithium disilicate crowns manufactured by CAD/CAM and the conventional heat-press technique

1. To produce 15 milled wax patterns which will be used for fabricating lithium disilicate crowns with the conventional heat pressed technique
2. To produce 15 milled monolithic lithium disilicate crowns (Ivoclar Vivadent IPS e.max CAD, Schaan, Liechtenstein)

The scanned STL file will be sent to a fabrication laboratory. The wax patterns and milled crowns will be manufactured by the same milling machine, i.e. Ivoclar PrograMill 7. The wax patterns will be fabricated with the dry milling option, while the crowns will be milled with the wet milling option.

From the milled wax patterns, a monolithic lithium disilicate crown will be heat-pressed (Ivoclar Vivadent IPS e.max Press, Schaan, Liechtenstein), according to the manufacturer's recommendations.

The 30 samples will be scanned with the ATOS II SO scanner (GOM, Germany) per the triple-scan protocol. The STL files will be used for alignment, registration, and subsequent fit assessment. There will be three different scans: 'Crown Solo', 'Master Die Solo', and 'Crown on Master Die'. After the objects are digitized to the STL's, the scanner software (ATOS system, GOM) will be used. First the 'Master Die Solo' STL and the 'Crown on Master Die' STL are registered by manual alignment by a best-fit registration. Then the same is done with the 'Crown Solo' STL and 'Crown on Master Die' STL. The final step is to delete the 'Crown on Master Die', and maintain the 'Crown Solo' STL with the 'Master Die Solo' STL for fit assessment.

To three dimensionally measure the cement space between the Crown and Die, the outer surface of the 'Crown Solo' STL is deleted, followed by measure the deviations of space between the intaglio and the surface of the 'Master Die Solo' STL.

The mean value of cement space will be measured three times. Statistical analysis will be performed with SPSS v11.5 (SPSS Inc., Chicago IL). The data measurements collected from each sample, within each group, will be reported in µm. Analysis will be completed using Paired t-test estimated at 95% level of confidence ($\alpha = .05$).

VII. REFERENCES

1. Beuer F, Edelhoff D, Gernet W, Naumann M. Effect of preparation angles on the precision of zirconia crown copings fabricated by CAD/CAM system. Dent Mater J 2008;27: 814-20.
2. Abduo J, Lyons K, Swain M. Fit of zirconia fixed partial denture: a systematic review. J Oral Rehabil 2010;37:866-76.
3. Shamseddine, L., et al. Marginal and internal fit of pressed ceramic crowns made from conventional and computer-aided design and computer-aided manufacturing wax patterns: An in vitro comparison. J Prosthet Dent, 2016
4. Miyazaki T, Hotta Y. CAD/CAM systems available for the fabrication of crown and bridge restorations. Aust Dent J 2011;56:97-106.
5. Ng J, Ruse D, Wyatt C. A Comparison of the marginal fit of crowns fabricated with digital and conventional methods. J Prosthet Dent 2014;112: 555-60.
6. Al-Rabab'ah MA, Macfarlane TV, McCord JF. Vertical marginal and internal adaptation of all-ceramic copings made by CAD/CAM technology. Eur J Prosthodont Restor Dent 2008;16:109-15.
7. Yüksel E, Zaimog!lu A. Influence of marginal fit and cement types on microleakage of all-ceramic crown systems. Braz Oral Res 2011;25:261-6.
8. Guess PC, Vagkopoulou T, Zhang Y, Wolkewitz M, Strub JR. Marginal and internal fit of heat pressed versus CAD/CAM fabricated all ceramic onlays after exposure to thermo-mechanical fatigue. J Dent 2014;42: 199-209.

9. Vojdani M, Torabi K, Farjood E, Khaledi A. Comparison the marginal and internal fit of metal copings cast from wax patterns fabricated by CAD/CAM and conventional wax up techniques. J Dent 2013;14:118-29.
10. Tan PL, Gratton DG, Diaz-Arnold AM, Holmes DC. An in vitro comparison of vertical marginal gaps of CAD/CAM titanium and conventional cast res- torations. J Prosthodont 2008;17:378-83.
11. Anadioti E, Aquilino SA, Gratton DG, Holloway JA, Denry I, Thomas GW, et al. 3D and 2D marginal fit of pressed and CAD/CAM lithium disilicate crowns made from digital and conventional impressions. J Prosthodont 2014;23:610-7.
12. Martinez-Rus F, Ferreiroa A, Ozcan M, Pradies G. Marginal discrepancy of monolithic and veneered all-ceramic crowns on titanium and zirconia implant abutments before and after adhesive cementation: a scanning elec- tron microscopy analysis. Int J Oral Maxillofac Implants 2013;28:480-7.
13. Baig MR, Tan KB, Nicholls JI. Evaluation of the marginal fit of a zirconia ceramic computer-aided machined (CAM) crown system. J Prosthet Dent 2010;104:216-27.
14. Stappert CF, Chitmongkolsuk S, Silva NR, Att W, Strub JR. Effect of mouth- motion fatigue and thermal cycling on the marginal accuracy of partial coverage restorations made of various dental materials. Dent Mater 2008;24: 1248-57.
15. Holmes JR, Bayne SC, Holland GA, Sulik WD. Considerations in measurement of marginal fit. J Prosthet Dent 1989;62: 405-8.
16. Holmes, JR., et al. Considerations in measurement of marginal fit. J Prosthet Dent, 1989. 62 (4): 405-408.

17. Schwartz, NL., et al. Unserviceable crowns and fixed partial dentures. JADA, Dec 1970. Vol. 81: 1395-1401.
18. Behrend DB. Crown margins and gingival health. Ann R Aust Co11 Dent Surg 1984;8:138-45.
19. Felton DA, Kanoy BE, Bayne SC, Wirthman GP. Effect of in vivo crown margin discrepancies on periodontal health.J Prosthet Dent 1991;65:357-64.
20. Tan PL, Gratton DG, Diaz-Arnold AM, Holmes DC. An in vitro comparison of vertical marginal gaps of CAD/CAM titanium and conventional cast restorations. J Prosthodont 2008;17:378-83.
21. Coli P, Karlsson S. Fit of a new pressure-sintered zirconium dioxide coping. Int J Prosthodont 2004;17:59-64.
22. Chan C, Haraszthy G, Geis-Gerstorfer J, Weber H, Huettemann H. Scanning electron microscopic studies of the marginal fit of three esthetic crowns. Quintessence Int 1989;20:189-93.
23. Reich S, Wichmann M, Nkenke E, Proeschel P. Clinical fit of all-ceramic three-unit fixed partial dentures, generated with three different CAD/CAM systems. Eur J Oral Sci 2005;113:174-9.
24. Bindl A, Windisch S, Mormann WH. Full- ceramic CAD/CIM anterior crowns and copings. Int J Comput Dent 1999;2:97-111.
25. Lin MT, Sy-Munoz J, Munoz CA, Goodacre CJ, Naylor WP. The effect of tooth preparation form on the fit of Procera cop- ings. Int J Prosthodont 1998;11:580-90.

26. Sulaiman F, Chai J, Jameson LM, Wozniak WT. A comparison of the marginal fit of In-Ceram, IPS Empress, and Procera crowns. Int J Prosthodont 1997;10:478-84.

27. May KB, Russell MM, Razzoog ME, Lang BR. Precision of fit: the Procera AllCeram crown. J Prosthet Dent 1998;80:394-404.

28. Assif D, Antopolski B, Helft M, Kaffe I. Comparison of methods of clinical evaluation of the marginal fit of complete cast gold crowns. J Prosthet Dent. 1985. Jul;54(1):20-4.

29. Rahme HY, Tehini GE, Adib SM, Ardo AS, Rifai KT. In vitro evaluation of the "replica technique" in the measurement of the fit of procera crowns. J Contemp Dent Pract. 2008 Feb 1;9(2):25-32.

30. Pelekanos S, Koumanou M, Koutayas SO, Zinelis S, Eliades G. Micro-CT evaluation of the marginal fit of different In-Ceram alumina copings. Eur J Esthet Dent 2009;4:278-92.

31. Boening KW, Wolf BH, Schmidt AE,Kastner K, Walter MH. Clinical fit of Procera AllCeram crowns. J Prosthet Dent 2000; 84:419-24.

32. Reich S, Wichmann M, Nkenke E, Proeschel P. Clinical fit of all-ceramic three-unit fixed partial dentures, generated with three different CAD/CAM systems. Eur J Oral Sci 2005;113:174-9.

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

34. Luthardt RG, Bornemann G, Lemelson S, Walter MH, Huls A. An innovative method for evaluation of the 3-D internal fit of CAD/CAM crowns fabricated after direct optical versus indirect laser scan digitizing. Int J Prosthodont 2004;17:680-5.

35. Luthardt RG, Bornemann G, Lemelson S, Walter MH, Huls A. An innovative method for evaluation of the 3-D internal fit of CAD/CAM crowns fabricated after direct optical versus indirect laser scan digitizing. Int J Prosthodont 2004;17:680-5.
36. Pelekanos S, Koumanou M, Koutayas SO, Zinelis S, Eliades G. Micro-CT evaluation of the marginal fit of different In-Ceram alumina copings. Eur J Esthet Dent 2009;4:278-92.
37. Nakamura T, Dei N, Kojima T, Wakabayashi K. Marginal and internal it of Cerec 3 CAD/CAM all-ceramic crowns. Int J Prosthodont 2003;16:244-8.
38. Kokubo Y, Ohkubo C, Tsumita M, Miyashita A, Vult von Steyern P, Fukushima S. Clinical marginal and internal gaps of Procera AllCeram crowns. J Oral Rehabil 2005;32:526-30.
39. Mitchell CA, Pintado MR, Douglas WH. Nondestructive, in vitro quantification of crown margins. J Prosthet Dent 2001; 85:575-84.
40. Bindl A, Mormann WH. Marginal and internal fit of all-ceramic CAD/CAM crown-copings on chamfer preparations. J Oral Rehabil 2005;32:441-7.
41. Swain MV, Xue J. State of the art of Micro-CT applications in dental research. Int J Oral Sci 2009;1:177-88.
42. Krasanaki ME, Pelekanos S, Andreiotelli M, Koutayas SO, Eliades G. X-ray microtomo-graphic evaluation of the influence of two preparation types on marginal fit of CAD/ CAM alumina copings: a pilot study. Int J Prosthodont 2012;25:170-2.
43. Zandparsa R, El Huni RM, Hirayama H, Johnson MI. Effect of different dental ceramic systems on the wear of human enamel: An in vitro study. J Prosthet Dent. 2016 Feb;115(2):230-7

44. Dindaroğlu F1, Duran GS2, Görgülü S3. Reproducibility of the lip position at rest: A 3-dimensional perspective. Am J Orthod Dentofacial Orthop. 2016 May;149(5):757-65

45. Tahmaseb A1, van de Weijden JJ, Mercelis P, De Clerck R, Wismeijer D. Parameters of passive fit using a new technique to mill implant-supported superstructures: an in vitro study of a novel three-dimensional force measurement-misfit method. Int J Oral Maxillofac Implants. 2010 Mar-Apr;25(2):247-57.

46. Drago C1, Saldarriaga RL, Domagala D, Almasri R. Volumetric determination of the amount of misfit in CAD/CAM and cast implant frameworks: a multicenter laboratory study. Int J Oral Maxillofac Implants. 2010 Sep-Oct;25(5):920-9

47. Holst S1, Karl M, Wichmann M, Matta RE. A new triple-scan protocol for 3D fit assessment of dental restorations. Quintessence Int. 2011 Sep;42(8):651-7.

48. Holst S1, Karl M, Wichmann M, Matta RE. A technique for in vitro fit assessment of multi-unit screw-retained implant restorations: Application of a triple-scan protocol. J Dent Biomech. 2012