JO JOURNAL OF OSSEOINTEGRATION periodontics and prosthodontics

Comparison of marginal fit and sealing ability of luted lithium disilicate crowns fabricated with CAD/CAM technology using two different intraoral scanners

G. VERNIANI, E. FERRARI CAGIDIACO, C. MARRUGANTI, P. KAMPOSIORA*, M. FERRARI

Department of Medical Biotechnologies, Division of Dental Materials and Fixed Prosthodontics, University of Siena, Italy
*National and Kapodistrian University of Athens, Greece

TO CITE THIS ARTICLE
Verniani G, Ferrari Cagidiaco e, Marruganti C, Kamposiora P, Ferrari M. Comparison of marginal fit ofand sealing ability of luted lithium disilicate crowns fabricated with CAD/CAM technology using two different intraoral scanners. J Osseointegr J Osseointegr 2021;13(4):S299-S304.

DOI 10.23805/JO.2021.13.S04.8

KEYWORDS Marginal fit; Sealing ability; Digital impressions.

ABSTRACT

Aim The aim of this *in vitro* study was to compare marginal fit discrepancy of lithium disilicate single crowns fabricated with computer-aided design and computer-aided manufacturing (CAD/CAM) technology using two digital impression systems.
Materials and methods 20 molars were prepared for the placement of lithium disilicate single crowns with vertical margins. Teeth were scanned using a model scanner, in order to create master scans. Then two intraoral scanners (IOS) were used to take impressions of all the 20 prepared teeth: Trios (3 Shape, Copenhagen, Denmark) and Aadva (GC, Tokyo, Japan), so that abutments were scanned with both devices. Then 40 lithium disilicate crowns were fabricated with CAD/CAM technology: each abutment had two crowns made with the two IOS. Then, 20 crowns (10 randomly selected from each IOS group) were luted to the 20 prepared teeth. The crowns were tested for marginal leakage by means of aluminum nitrate solution. Then, teeth were embedded in self-curing transparent resin and cut into 1 mm thick slices by means of a low speed, precision cutting machine (Buehler Isomet) using a diamond blade. The slices of each tooth were observed under optical microscope to evaluate the amount of leakage, if any. Then, the slices were sputter coated with gold and observed under scanning electron microscope (SEM) to evaluate the thickness of the cement at the margins.
Results No statistically significant differences were found, neither regarding the nanoleakage of the crowns made with the two tested IOS nor regarding cement thickness. Measurements of cement thickness were on average within the acceptable limits considered.
Conclusions Both IOS tested showed good performances and, from the results of this *in vitro* study, can be considered useful for clinical application.

INTRODUCTION

For many years traditional impressions have been performed in everyday practice to fabricate complete coverage crowns with great results (1), but lately many technological advances upgraded the performance of intraoral scanners. Nowadays, the level of optical impressions is as accurate as or even better than the traditional ones for the fabrication of fixed restorations (2), especially when working with supragingival margins (3,4). Key factors for long-term clinical success of complete crowns are function preservation, biocompatibility, marginal and internal fit and fracture resistance. Marginal fit is one of the main factors in the success of the restoration because any discrepancy leads to marginal gap and, subsequently, to microleakage, cement dissolution by oral fluids, and biofilm accumulation, with consequences such as caries or endodontic and periodontal problems (5,6,7). The maximum width of the marginal gap has not been universally set with precision; many studies consider acceptable gaps until 200 µm, but fixed restorations with marginal discrepancies of less than 120 µm are considered more likely to be successful (8). Anyway, the marginal gap should be as small as possible.
In traditional fixed prosthodontics, polyether and polyvinyl siloxane are the most used materials for the definitive impression of the prepared abutment, from which the gypsum model is made for the fabrication of the restoration. The final result is strongly affected by dimensional changes of impression materials and gypsum due to variation in temperature, time elapsed between impression taking and pouring, surface wettability of the gypsum product, and disinfection procedures (9,10). All these possible liabilities in the traditional procedure are eliminated in the digital one. The introduction of digital impressions by means of intraoral scanners (IOS) has

thoroughly changed the workflow because patients' anatomy is directly acquired and transformed in a .stl file that can be sent to the lab in a few minutes. In the digital workflow, the technicians work directly on the .stl file (CAM, computer-aided design step) and, once the digital project is ultimated, they send the project to the CAM (computer-aided manufacturing) machine so that the final restoration is milled.

Advances in both CAD-CAM technology and in the new materials used, such as zirconia and lithium disilicate, have led to the production of more accurate fixed milled restorations (11,12,13).

The use of IOS, beside producing good restorations, has many other advantages, such as: less time-consuming impression taking and transportation to the lab, real time visualization, easy and selective repeatability, no need to disinfect dental impressions and no wear of the model (14,15). Currently, many different scanners are on the market, so the purpose of this *in vitro* study was to evaluate the marginal fit of crowns made from impressions taken by two different IOSs.

The aim of the study was in fact to compare lithium disilicate full crowns made by using two different devices, in terms of marginal fit and sealing ability.

The null hypotheses tested were:

1) marginal precision and sealing ability are statistically different between the two groups of lithium disilicate crowns;

2) marginal cement thickness of the two groups of lithium disilicate crowns shows statistically significant differences.

MATERIALS AND METHODS

A sample of 20 intact human molars, extracted for therapeutic reasons and stored in saline solution, were prepared with appropriate tooth reduction for a complete crown and a vertical finishing line. The abutments were then included in 20 customized supports made of putty polyvinyl siloxane and scanned with a lab scan for control. All 20 teeth were scanned again with the two IOSs and 40 digital impressions were obtained: 20 using Trios (3Shape, Copenhagen, Denmark) and 20 using Aadva (GC, Tokyo, Japan) according to the manufacturers protocols. The 40 .stl files obtained were then sent electronically to the technician that performed the CAD phase and then to a centralized milling center for the fabrication of 40 complete lithium disilicate crowns.

From the 40 lithium disilicate crowns produced (20 from Trios 3 Basic 3 and 20 from Aadva), only 20, 10 from each group, were randomly selected to be luted to the abutments as follows.

- Group 1: Abutments 3, 8, 10, 12, 14, 15, 16, 17, 19, 20 were restored with Trios crowns.
- Group 2: Abutments 1, 2, 4, 5, 6, 7, 9, 11, 13, 18 were restored with Aadva crowns.

For luting the lithium disilicate crowns the following adhesive protocol was used: 9% hydrofluoric acid in the internal part of the crown, wash, dry and primer with silane, 37% orthophosphoric acid on the abutment, wash, dry, adhesive, polymerization. The cement was placed in the internal part of the crowns, which were then seated on the abutments and light-cured from all sides.

Samples underwent ammoniacal silver nitrate microleakage procedure in order to evaluate microleakage at the crowns margins. The teeth were covered with red nail polish on all the surface except the margins between the crown and the abutment. Then, they were immersed in an ammoniacal silver nitrate solution diluted with distilled water (ratio 1:4) and left there for 24 hours. After that, teeth were rinsed thrice in tap water for 10 minutes and then removed the nail polish was removed. Teeth were immersed in a photo-developer solution diluted with distilled water (1:10) for 8 hours and then rinsed thrice in tap water for 10 minutes each time. The teeth were embedded in transparent self-curing acrylic resin and then sliced with a low-speed diamond saw (Buehler Isomet) under watercooling, in order to obtain 1 mm thick slices cut along their long axis and perpendicularly to the proximal margins. The observation of the margins was performed on every section. Marginal microleakage was carefully evaluated with an optical microscope and scored according to the following grade scale:

0: no microleakage;
1: 0% to 20% of gingival floor interface showing nanoleakage;
2: 20% to 40% of gingival floor interface showing nanoleakage;
3: 40% to 60% of gingival floor interface showing nanoleakage;
4: 60% to 80% of gingival floor interface showing nanoleakage;
5: 80% to 100% of gingival floor interface showing nanoleakage.

The scores of the microleakage test of crowns on dentin and enamel were analyzed. Since the data did not pass the Shapiro-Wilk's test ($p<0,05$), the Mann-Whitney U test was performed. In all tests the level of statistical significance was set at $p<0,05$.

Wilcoxon signed-rank test was performed to assess the absence of clinically significant d ifferences b etween the scores of microleakage registered on dentin and on enamel under the crowns made from the digital impressions performed with the same scanner.

After the observation under optical microscope (Fig. 1) samples were processed for SEM analysis (Fig. 2) as follow: first, they were etched with 37% orthophosphoric acid, washed and dried, then they underwent vacuum sputter coating with gold. The samples were then observed, once again, under electronical microscope in order to

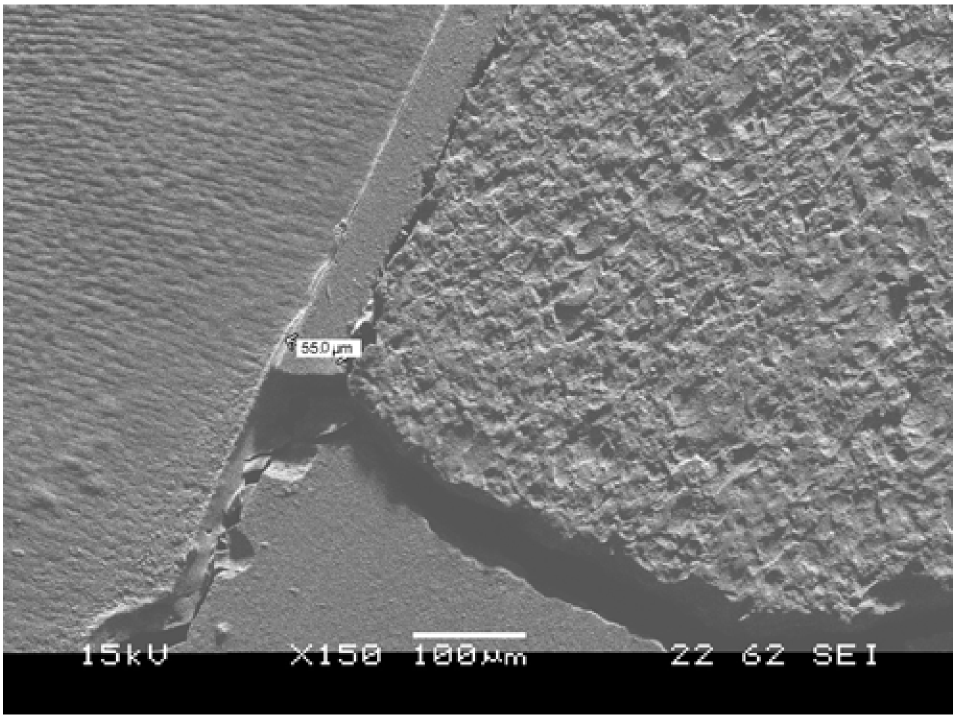

FIG. 1 Optical microscope image of crown margins.

FIG. 2 SEM image of cement thickness measurement.

evaluate margins at higher magnification and measure cement thickness in two sites. Cement thickness was analyzed with Student's t test, after validating the assumptions of normality (Shapiro-Wilk's test, $p>0.05$) and variance (Levene's test, $p>0.05$) homogeneity in the two groups.

RESULTS

The results of the infiltration at the margins in enamel and dentin are reported in Table 1.
Cement thickness of both groups is reported in Tables 2 and 3. The Aadva group showed lower cement thickness than the 3Shape group at the cervical margins, although this was not statistically significant.
The Wilcoxon signed-rank test was applied to the microleakage scores. In enamel, the scores were 0 under all crowns.
Table 4 reports the scores of microleakage recorded on dentin. The Mann-Whitney test did not find any statistically significant differences between the performance of the two IOSs as regards dentin infiltration ($p=0,527$).
Table 5 reports microleakage scores on dentin and enamel under the crowns made from the impressions taken with Aadva (GC).
Table 6 reports microleakage scores on dentin and enamel under the crowns made from the impressions taken with Trios 3Shape.

Crown GC Group 2	slice	enamel	dentin	Crown 3Shape Group 1	slice	enamel	dentin
1	1)	0	0	3	1)	0	1
	2)	0	0		2)	0	0
	3)	0	0		3)	0	0
	4)	0	0		4)	0	0
	5)	0	0		5)	0	0
	6)	0	0				
	7)	0	0				
	8)	0	3				
2	1)	0	2	8	1)	0	0
	2)	0	2		2)	0	0
	3)	0	0		3)	0	0
	4)	0	0		4)	0	0
	5)	0	0		5)	0	0
	6)	0	2		6)	0	0
4	1)	0	0	10	1)	0	0
	2)	0	0		2)	0	0
	3)	0	0		3)	0	0
	4)	0	0		4)	0	0
	5)	0	0		5)	0	0
	6)	0	0		6)	0	0
5	1)	0	0	12	1)	0	0
	2)	0	0		2)	0	0
	3)	0	2		3)	0	0
	4)	0	0		4)	0	0
	5)	0	0		5)	0	0
	6)	0	0		6)	0	0
6	1)	0	0	14	1)	0	0
	2)	0	0		2)	0	0
	3)	0	0		3)	0	3
	4)	0	0		4)	0	0
	5)	0	0		5)	0	0
	6)	0	0		6)	0	0

Crown GC Group 2	slice	enamel	dentin	Crown 3Shape Group 1	slice	enamel	dentin
7	1)	0	0	15	1)	0	0
	2)	0	0		2)	0	0
	3)	0	0		3)	0	0
	4)	0	0		4)	0	0
	5)	0	0		5)	0	0
	6)	0	0		6)	0	0
9	1)	0	0	16	1)	0	0
	2)	0	0		2)	0	0
	3)	0	0		3)	0	0
	4)	0	0		4)	0	0
	5)	0	0		5)	0	0
	6)	0	0		6)	0	0
11	1)	0	0	17	1)	0	0
	2)	0	0		2)	0	0
	3)	0	0		3)	0	0
	4)	0	0		4)	0	0
	5)	0	0		5)	0	0
	6)	0	0		6)	0	0
13	1)	0	0	19	1)	0	0
	2)	0	0		2)	0	0
	3)	0	0		3)	0	0
	4)	0	0		4)	0	0
	5)	0	0		5)	0	0
	6)	0	0		6)	0	0
18	1)	0	0	20	1)	0	0
	2)	0	0		2)	0	0
	3)	0	0		3)	0	4
	4)	0	0		4)	0	0
	5)	0	0		5)	0	0
	6)	0	0		6)	0	0
average		0	0,17741935483871			0	0,135593220338983

TABLE 1 Score of nanoleakage of each tooth.

The Wilcoxon signed-rank test did not find any statistically significant differences between the microleakage scores recorded on dentin and enamel, neither under the crowns made from Aadva (p=0,063) nor under the crowns made from Trios (p=0,25).
Tables 7 and 8 report the descriptive statistics of cement thickness measured in microns and the statistical significance of the differences between the two experimental groups in this variable.

DISCUSSION

According to the results of this study the null hypothesis that statistically significant differences would be found in the marginal fit of lithium disilicate crowns fabricated with the two IOS is rejected. In this study, the fit of crowns was assessed by means of microleakage of aluminum nitrate solution through the margins between the restoration and the abutment and on cement

	cervical margin A	cervical margin B
1	110	90
2	55	75
4	60	55
5	75	65
6	55	70
7	110	90
9	100	120
11	125	135
13	100	90
18	75	65
average	86,5	85,5

TABLE 2 Cement thickness of Aadva.

	cervical margin A	cervical margin B
3	55	65
8	70	75
10	55	70
12	75	105
14	120	130
15	135	95
16	115	90
17	105	120
19	105	105
20	120	130
average	95,5	98,5

TABLE 3 Cement thickness of Trios.

SCANNER	N	median	interquartile range
GC IOS	62	0	0-0
3Shape	59	0	0-0

TABLE 4 Scores of microleakage registered on dentin.

GC	N	median	interquartile range
Enamel	62	0	0-0
Dentin	62	0	0-0

TABLE 5 Microleakage scores on dentin and enamel under crowns made from the impression performed with Experimental Aadva.

3Shape	N	median	interquartile range
Enamel	59	0	0-0
Dentin	59	0	0-0

TABLE 6 Microleakage scores on dentin and enamel under crowns made from the impression performed with Trios.

Scanner	N	average	standard deviation	statistical significance
3Shape	10	95.5	29.19	NS (p=0.47)
GC	10	86.5	25.60	
*NS=statistically not significant difference, *=statistically significant difference*				

TABLE 7 Descriptive statistics of cement thickness measured in µm at cervical margin A.

Scanner	N	average	standard deviation	statistical significance
3Shape	10	98.5	23.81	NS (p=0.25)
GC	10	85.5	25.43	
*NS=statistically not significant difference, *=statistically significant difference*				

TABLE 8 Descriptive statistics of cement thickness measured in µm at cervical margin B.

thickness at the margins measured at SEM.
It is necessary to consider that marginal fit depends on different factors, among which the fabrication process from the preparation design to the cementation methods (16). Therefore, the differences in scanning precision, or CAD software may also affect fit accuracy (17).
Marginal fit discrepancies, due to an imprecise impression of the abutment, can only be filled with cement, which is susceptible to dissolution (18). For this reason, the precision of the intraoral scanner in the impression of the abutment is fundamental. Analysis of the results of this study suggests that the marginal fit of lithium disilicate crowns fabricated with the fully digital method with the two IOSs are comparable between them and in line with the fit parameters set for crowns made with the conventional method. In fact, no statistically significant differences were found between cement thickness of the two groups of crowns.
The ability to directly visualize and measure marginal discrepancy by means of SEM photography provided accuracy and reproducibility and the possibility to see

imperfections of the restoration at a high resolution have been used only in a few other studies.
Furthermore, the marginal fit was indirectly evaluated by means of an infiltration procedure of the cement and observing microleakage under the crowns. As stated by Pioch the term "nanoleakage" was introduced to describe a specific type of leakage within the dentin margin of the restoration (19). Consequently, the sealing ability and resistance to the varying stresses of luting agents used to cement the crown are extremely important and the thickness of cement exposed to the oral fluids should be the lowest possible (20).
It is commonly believed that increased adaptation of the crown leads to lower leakage, as it may lead to an increase in the cement dissolution, with a potential for leakage (17).
From the results of the present study no statistically significant difference was found between the infiltration scores of the two groups of crowns made with the two IOSs. Both tested devices showed good performances in this in vitro study, but further studies should be carried out to evaluate the performance of the devices in intraoral conditions, because many clinical factors can affect the precision such as patient and hand movements during scanning as well as the presence of saliva and reflections from tooth and adjacent structures (21-25).

CONCLUSIONS

The two tested intraoral scanner systems showed comparable levels of precision in the impressions taken for lithium disilicate complete coverage crowns regarding marginal fit. Further studies are needed to validate the accuracy of these scanners under clinical conditions.

REFERENCES

1 Joda T, Zarone F, Ferrari M. The complete digital workflow in fixed prosthodontics: a systematic review. BMC Oral Health 2017 Sep 19;17(1 :124.
2 Pecciarini, M, Biagioni A, Ferrari, M. A systematic review of clinical trials on digital impression of prepared teeth. J Osseointegr 2019;112:92–97.
1 Chochlidakis KM, Papaspyridakos P, Geminiani A, Chen CJ, Feng IJ, Ercoli C. Digital versus conventional impressions for fixed prosthodontics: A systematic review and meta-analysis. J Prosthet Dent 2016 Aug;116(2 :184-190.e12.
2 Ferrari Cagidiaco E, Zarone F, Discepoli N, Joda T, Ferrari M. Analysis of the reproducibility of subgingival vertical margins using intraoral optical scanning (IOS : A randomized controlled pilot trial. J Clin Med. 2021 Mar 1;10(5 :941.
3 Gardner FM. Margins of complete crowns--literature review. J Prosthet Dent 1982 Oct;48(4 :396-400.
4 Larson TD. The clinical significance of marginal fit. Northwest Dent 2012 Jan-Feb;91(1 :22-9.
5 Bader JD, Rozier RG, McFall WT Jr, Ramsey DL. Effect of crown margins on periodontal conditions in regularly attending patients. J Prosthet Dent 1991 Jan;65(1 :75-9.
6 McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J 1971 Aug 3;131(3 :107-11.
7 Thongthammachat S, Moore BK, Barco MT 2nd, Hovijitra S, Brown DT, Andres CJ. Dimensional accuracy of dental casts: influence of tray material, impression material, and time. J Prosthodont 2002 Jun;11(2 :98-108.
8 Johnson GH, Craig RG. Accuracy of four types of rubber impression materials compared with time of pour and a repeat pour of models. J Prosthet Dent 1985 Apr;53(4 :484-90.
9 Zarone F, Ferrari M, Mangano FG, Leone R, Sorrentino R. Digitally Oriented Materials: Focus on lithium disilicate ceramics. Int J Dent 2016;2016:9840594.
10 Strub JR, Rekow ED, Witkowski S. Computer-aided design and fabrication of dental restorations: current systems and future possibilities. J Am Dent Assoc 2006 Sep;137(9 :1289-96.
11 Pradíes G, Zarauz C, Valverde A, Ferreiroa A, Martínez-Rus F. Clinical evaluation comparing the fit of all-ceramic crowns obtained from silicone and digital intraoral impressions based on wavefront sampling technology. J Dent 2015 Feb;43(2 :201-8.
12 Zimmermann M, Mehl A, Mörmann WH, Reich S. Intraoral scanning systems - a current overview. Int J Comput Dent 2015;18(2 :101-29.
13 Joda T, Lenherr P, Dedem P, Kovaltschuk I, Bragger U, Zitzmann NU. Time efficiency, difficulty, and operator's preference comparing digital and conventional implant impressions: a randomized controlled trial. Clin Oral Implants Res 2017 Oct;28(10 :1318-1.
14 Shembesh M, Ali A, Finkelman M, Weber HP, Zandparsa R. An In Vitro Comparison of the Marginal Adaptation Accuracy of CAD/CAM Restorations Using Different Impression Systems. J Prosthodont 2017 Oct; 26(7 :581-586.
15 Kale E, Seker E, Yilmaz B, Özcelik TB. Effect of cement space on the marginal fit of CAD-CAM-fabricated monolithic zirconia crowns. J Prosthet Dent 2016 Dec; 116(6 :890-895.
16 Jacobs MS, Windeler AS. An investigation of dental luting cement solubility as a function of the marginal gap. J Prosthet Dent 1991 Mar;65(3 :436-42.
17 Pioch T, Staehle HJ, Duschner H, Garcia-Godoy F. Nanoleakage at the composite-dentin interface: a review. Am J Dent 2001 Aug;14(4 :252-8.
18 Gu XH, Kern M. Marginal discrepancies and leakage of all-ceramic crowns: influence of luting agents and aging conditions. Int J Prosthodont Mar-Apr 2003;16(2 :109-16.
19 Shiratsuchi H, Komine F, Kakehashi Y, Matsumura H. Influence of finish line design on marginal adaptation of electroformed metal-ceramic crowns. J Prosthet Dent 2006;95(3 :237–42.
20 Keeling A, Wu J, Ferrari M. Confounding factors affecting the marginal quality of an intra-oral scan. J Dent 2017 Apr;59:33-40.
21 Ferrari Cagidiaco E, Grandini S, Goracci C, Joda T. A pilot trial on lithium disilicate partial crowns using a novel prosthodontic functional index for teeth (FIT). BMC Oral Health 2019;19 (1): 276.
22 Strauß P, Mosch R, Sandmaier M, Von See C. Intraoral scanner accuracy: the influence of manual movement? J Osseointegr 2021;13(4 Supplement):S285-S288.
23 Skordou T, Kebi L, Osnes C, Keeling A. The effect of two different milling instrument sets on cad proposed cement thickness and fit surface of chairside cad crowns. J Osseointegr 2021;13(4 Supplement):S271-S278.
24 Al Ibrahim I, Keeling A, Osnes C. The effect of operator scanning speed on the trueness and precision of full-arch digital impressions captured in vitro using an intraoral scanner. J Osseointegr 2021;13(4 Supplement):S265-S270.
25 Sorrentino R, Ruggiero G, Leone R, Ferrari M, Zarone F. Area accuracy gradient and artificial markers: a three-dimensional analysis of the accuracy of IOS scans on the completely edentulous upper jaw. J Osseointegr 2021;13(4 Supplement):S257-S264.