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Original Article

Evaluation of the marginal fit of monolithic crowns fabricated by direct and indirect digitization

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Abstract

Purpose: To evaluate the influence of intraoral and extraoral digitization systems on marginal discrepancy of monolithic lithium disilicate and monolithic zirconia computer-aided design-computer-aided manufacturing (CAD-CAM) crowns.

Methods: Forty standardized machined stainless steel specimens with the characteristics of a first molar were manufactured and randomly assigned to two groups (n=20 each), depending on their material: monolithic lithium disilicate ceramic (LM), and monolithic zirconia (ZM). Then, each group was subdivided into two depending on the scanning system used: intraoral scanner (IOS), and extraoral scanner (EOS). The digitization process was standardized with two methacrylate devices, one for each scanner. After scanning and manufacturing of the crowns, the marginal discrepancy was measured under a scanning electron microscope (SEM). Data analysis was made using two-way analysis of variance (ANOVA) and the effect size with Cohen's d.

Results: All the measurements were within the limits considered acceptable. Regardless the restorative material significant differences between scanners were observed, being the effect from low to moderate. However, no differences were observed between the scanners in either the lithium disilicate or zirconia group.

Conclusions: The intraoral scan showed lower marginal discrepancy than the extraoral scan in CAD-CAM monolithic crowns, but these differences were not observed in each of the ceramic systems.

Keywords: *Marginal fit, monolithic crowns, CAD/CAM, digital impression, intraoral scanner*

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1. Introduction

Due to increased demand among patients for esthetic and biocompatible materials, the use of metal-free ceramic-based restorations has grown [1]. Typically, in order to achieve a more natural appearance, ceramic restorations with a high-strength ceramic core coated with feldspar ceramic were used [2,3]. However, ceramic posterior crowns present a number of drawbacks such as different toughness between core and veneer, the bond between them, a multistep manufacturing process, or residual tensile stresses [4]. Therefore, in order to avoid these problems, monolithic crowns have been developed [5].

Monolithic crowns present some advantages as better cost-effectiveness, less manufacturing time [6], and higher dental tissue saving compared to veneered crowns due to lower ceramic thickness needed [7]. Nevertheless, they also have certain limitations such as greater fragility, repair capacity [8] or limited esthetics [3]. Monolithic zirconia crowns are an alternative to metal crowns in posterior regions [8], but in relation to aesthetics, they present certain limitations. In this sense, monolithic lithium disilicate materials show exceptional aesthetics without the need of veneering [9]. These monolithic crowns can be manufactured using computer-aided design-computer-aided manufacturing (CAD-CAM) technology [10], since ceramics are one of the materials that can be processed using these technologies [11].

Nowadays, different advances in technology have made CAD-CAM systems with reliable scanners and sophisticated software [12]. Thus, these systems must produce restorations with a marginal accuracy comparable to the one achieved with traditional manufacturing processes [13]. Marginal fit has been considered one of the most important criteria for assessing the success of restorations [14], together with aesthetics and fracture resistance [15]. It is necessary to take into account that the marginal fit depends on different factors [16,17], among which the fabrication process from the preparation design to the cementation method is found [18]. Therefore, the differences among scanning precision, or CAD software may also influence the accuracy of the fit [19]. Nevertheless, there is no consensus on what the acceptable marginal gap should be [20].

Inconsistent results have been observed among different studies that analyzed the marginal discrepancy of restorations manufactured with different CAD-CAM systems [21].In particular, for CAD-CAM crowns margins of less than 90 µm [22], or ranges between 50 and 100 µm [23] have been described. Boitelle et al. [13] reported, in their systematic review, that in CAD-CAM restorations it is possible to achieve a marginal discrepancy of less than 80 µm. Furthermore, few studies have evaluated

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the marginal discrepancy between two CAD-CAM systems in monolithic ceramic systems [3], and no previous studies have been found regarding the influence of the digitization system in different monolithic systems.

Therefore, the aim of this study was to analyze the influence of intraoral and extraoral digitization systems on the marginal discrepancy of lithium disilicate and zirconia monolithic CAD-CAM crowns. The null hypothesis established that there would be no significant differences in the marginal discrepancy between the scanning systems in terms of marginal discrepancy.

2. Materials and methods

2.1. Manufacturing of the specimens

Forty standardized machined stainless steel specimens were fabricated. The features were introduced in the design program (AutoCAD 2011, Autodesk, San Rafael, CA, USA). The specimens were manufactured to simulate the clinical characteristics of a first prepared mandibular molar with a 6º angle of convergence of the axial walls, 1-mm-width chamfer, and a circumferential finishing line. The machining was carried out with a numerical control lathe (EMCO Turn 342, EMCO Group, Hallein, Austria), governed by a software (SINUMERIK, Siemens AG, Munich, Germany), from stainless steel 316L Alloy (UNS S3 1603) rods.

Each specimen was positioned on a metal base and randomly divided into two groups depending on the restorative material (n = 20 per group): monolithic lithium disilicate (LM) and monolithic zirconia (ZM). Then, specimens from each group were subdivided into two groups depending on the scanning system used (n = 10 each): intraoral scanner (IOS) and extraoral scanner (EOS). The materials used in the study are summarized in Fig. 1 and Table 1. The specimens were fabricated in the mechanical Workshop of the Physical Science Faculty (PSF) (University Complutense of Madrid, Spain) (UCM).

2.2 Scanning process

In the study the software version 5.1.1 of the IOS was used. Both scanners were previously calibrated according to the manufacturer´s guidelines [24-27]. In order to standardize the digitization process of the specimens and reduce operator intervention, two methacrylate devices were fabricated at the PSF, one for the intraoral digitization process and the other one for the extraoral digitization process (Fig. 2). The devices were manufactured from methacrylate plates (Kondia K-76, Kondia, Elgoibar, Spain). The methacrylate device for the IOS presented a central area to position the specimen, different support areas to locate the handle and a light cover to avoid light reflection and simulate more the light of the oral cavity. The same scanning strategy was carried out to optimize and standardize the conditions of the study [28]. Similarly, the methacrylate device for the EOS presented a central area for the specimen placement and a hemi-branded shape to adapt to the scanner platform. The scans were performed by the same trained operator to improve repeatability and avoid possible discrepancies [24-27].

Prior to the scanning process with both scanners, the surface of each die was powdered with titanium dioxide particles (Lava Powder, 3M ESPE) to decrease the light reflection [3,25,29-31]. To perform the digitization with the IOS, the base with the die was placed in the middle of the device whereas the handle was positioned on different support areas following always the same protocol. With the base perpendicular to the first area, the handle was positioned also in that area, beginning the scanning process by digitizing the occlusal surface. Without stopping the scanning, the handle was moved to the second area where the distal surface was digitized first and the mesial surface secondly. Then, the scanning process was paused and when the base was placed perpendicular to the second area, the scanning process was resumed to scan the lingual and the buccal surfaces (Fig. 2a,b,c,d,e). To carry out the digitization with the EOS, the extraoral device was placed in the scanner platform as the design was made to fit into it (Fig. 2f). The scan was then performed according to the manufacturer's instructions. The virtual dies were reviewed in the screen attached to each scanner analyzed for completeness and artifacts before acceptance [20,32]. When the images were accepted the point cloud was transformed into standard triangulation language (STL) files. The images that were not accepted were deleted and the scan was repeated.

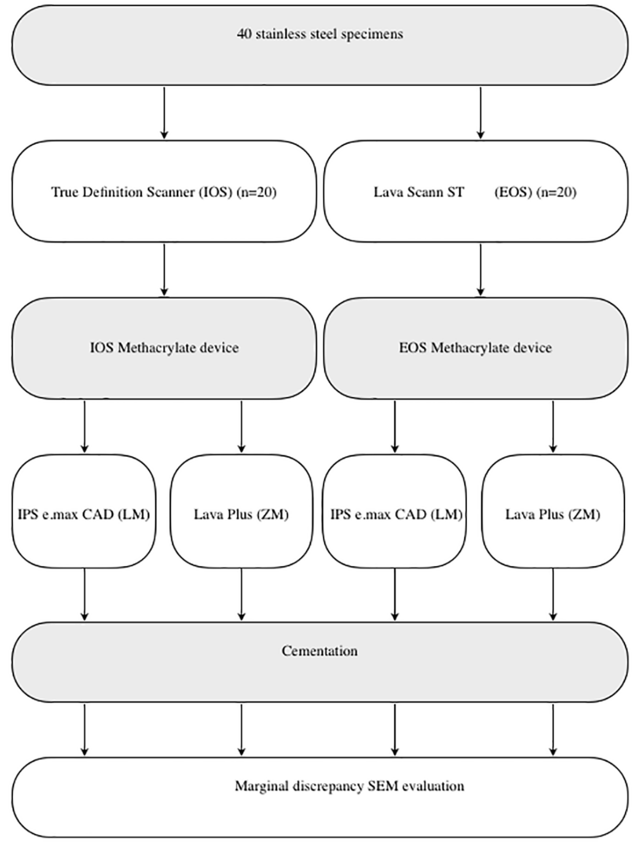

Fig. 1. Investigation flow chart. IOS, intraoral scanner; EOS, extraoral scanner; LM, Lithium disilicate monolithic; ZM, zirconia monolithic; SEM, scanning electron microscope.

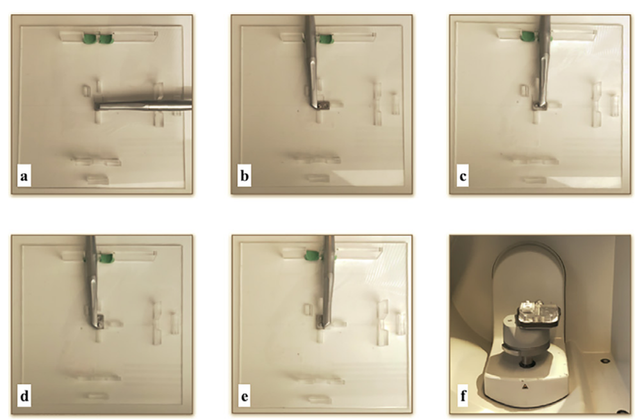

Fig. 2. Scanning strategy for IOS and EOS with the methacrylate devices. IOS scanning process: (a) Occlusal surface. (b) Distal surface. (c) Mesial surface. (d) Lingual surface. (e) Buccal surface. (f) Methacrylate device for EOS scanning procedure.

Table 1. Scanners, restorative materials, groups, manufacturers, sample size, mean marginal discrepancy, and standard deviation (SD).

	Restorative material	Brand	Manufacturer	n	Marginal gap (μm) Scanner	
					Mean	SD
IOS		True Definition Scanner	3M ESPE, Seefeld, Germany	20	35,21	14,87
EOS		Lava Scann ST	3M ESPE, Seefeld, Germany	20	48,58	16,93
IOS	LM	IPS e.max CAD	IIvoclar Vivadent, Schäan, Liechtenstein	10	39,41	16,45
IOS	ZM	Lava Plus	3M ESPE, Seefeld, Germany	10	31,01	12,54
EOS	LM	IPS e.max CAD	IIvoclar Vivadent, Schäan, Liechtenstein	10	49,75	10,20
EOS	ZM	Lava Plus	3M ESPE, Seefeld, Germany	10	47,40	22,32

IOS, intraoral scanner; EOS, extraoral scanner. LM, lithium disilicate monolithic; ZM, zirconia monolithic.

2.3 Fabrication of the crowns

The crowns were designed using CAD software (DWOS version 7.0, Dental Wings Inc., Monteral, Canada). The anatomy of a first mandibular molar was selected from the software library. The cement space was set at 50 µm, and the crowns thickness was set at 1 mm at the axial walls and 1.5 mm at the occlusal surface. To compensate the postsintering shrinkage, the design was enlarged by 20% in zirconia crowns. To fabricate the LM crowns the information was sent to the milling software (Zenotec CAM 3.2, Wieland Dental, Pforzheim, Germany), milled in the milling unit (Wieland Zenotec, Wieland Dental) and vitrified in a furnace (Programat, Ivoclar Vivadent). The ZM crowns were manufactured from pre-sintered zirconia blocks, milled in a milling unit (Lava Form, 3M ESPE) and sintered for 4 hours at 1500° (Lava Therm, 3M ESPE). The crowns were cemented to the specimens with resin cement (RelyX, 3M ESPE) following the manufacturer's instructions, at room temperature (18 to 24°C) and relative humidity (50 ± 10%). A constant seating load of 10 N was applied with a torque wrench (820/70, USAG, Gemonio, Italy) for 10 minutes [3,33]. Both materials were cemented following the same systematic procedure to avoid confounding factors [34].

2.4. Marginal discrepancy evaluation

Vertical marginal gap was measured under a scanning electron microscope (SEM) (JSM 6400, JEOL Tokyo, Japan) in the ICTS National Electron Microscopy Centre (UCM, Spain). To avoid distortion of the electrons, the specimens were coated with 24 kt gold by a metallizer (Q15RS, Quorum Technologies, Sussex, UK). Once inside the SEM, an image with 500x magnification was obtained by an energy dispersal detector (Link Pentafet, Oxford Instruments, Abingdom, UK). The image was transferred to a personal computer with software (INCA Suite 4.04, Oxford Instruments; Abingdom, UK) that captured and digitalized the image and then, a second image was obtained with a measurement expressed in microns. To standardize the measuring area, the marginal fit was measured at the same point in the middle of the buccal and lingual surfaces that was marked with an indelible marking pen (Lumocolor permanent, Staedler Mars, Nuernberg, Germany), to ensure repeatable positions for all crowns [3,33,35-38]. To increase the number of measurements per specimen, the images were edited (Adobe Photoshop CS6, Adobe Systems, San Jose, CA, USA) creating 29 lines parallel to the original [3,33]. Measurements were performed with a scale of 1:300 (Faber Castell, Stein, Germany). To determine the marginal discrepancy of each crown, the average of the 60 measurements (30 per surface) was used.

2.5. Statistical analysis

The statistical analysis was performed with a statistical software (IBM SPSS Statistics, version 25.0, IBM, Armonk, NY, USA), and statistical significance was established at $\alpha = 0.05$. In order to analyze the marginal discrepancy between the digitizing systems, the distribution was evaluated by Shapiro-Wilk Test, the variance homogeneity through the Levene Test, and the independence of the data was analyzed by a two-factorial analysis of variance (ANOVA). Data presented a normal distribution, variance homogeneity, and no interaction between the digitization systems and the restorative materials was observed. Student t-test was applied to evaluate the overall marginal discrepancy between the digitizing systems, and in each of the ceramic groups. In addition, the effect size was evaluated using Cohen's d

3. Results

All marginal discrepancy values obtained are within the limits considered acceptable. Table 1 shows the marginal discrepancy data of the study groups. The overall mean marginal gap was 41,01 ± 15,38 µm. No interaction was observed between the scanning systems and the ceramic materials ($p = 0,555$) (Fig. 3). In addition, significant differences were showed between the scanning systems ($p < 0,05$). Regardless of the ceramic material, crowns digitalized with the IOS presented lower marginal discrepancy than those digitalized with the EOS ($p = 0,012$) (Table 2). The effect size was from low to moderate ($d = 0,86$). Regarding LM group, no significant differences between intraoral and extraoral digitization were observed ($p > 0,05$). In a similar way, when evaluating the marginal discrepancy of the ZM group, no significant differences were noted between both scanners ($p > 0,05$) (Fig. 4).

4. Discussion

This study analyzed the behavior of two digitization systems regarding the marginal discrepancy of monolithic ceramic crowns. The null hypothesis was partially accepted since significant differences were observed in the marginal discrepancy between two digitization systems independently of the ceramic system, but no differences were observed in the discrepancy between the digitization systems neither in the LM crowns nor in the ZM crowns.

CAD-CAM methods have led to great advances in restoration production [39]. Furthermore, the emerging evidence indicates that all-ceramic restorations might be a viable alternative to metal-ceramic restorations [40]. In addition, current advances in material science have contributed to the synergy of CAD-CAM with new monolithic materials [41]. Clinically, digitization arises as an alternative to conventional impression techniques [22] and allows direct scanning of the oral cavity. In the laboratory, the digital impression process is implemented by scanning the cast model or by digitizing the impression itself [42].

Therefore, when analyzing the marginal fit of CAD-CAM restorations, different factors associated with this technology must be taken into account. Adjustment parameters, software versions [21,27], or the accessibility of the handle in the intraoral scanning procedure [20,26,29,31,43] could affect the marginal fit. The handle used in the study is smaller than other IOSs, representing an advantage for the scanning of posterior regions [29]; although, as the study was conducted using a scanning device, the accessibility of the handle was complete and did not influence the results. However, it is also necessary to consider other factors that may influence the marginal discrepancy results such as the diverse methodologies used in the studies published in literature [3], as well as the clinical factors [32].

The present study was conducted in vitro, and metal dies combined with two digitizing devices were used to obtain reproducible and standardized results. This design tried to reduce possible errors. The metallic abutments were not ideal to be digitally scanned, but they were covered with titanium oxide for constant reflectivity followingthe manufacturer guidelines [3,25,30,31]. The conventional impression technique with the posterior scanning in the dental laboratory may be associated with dimensional changes derived from the impression material and the model c asting [44],

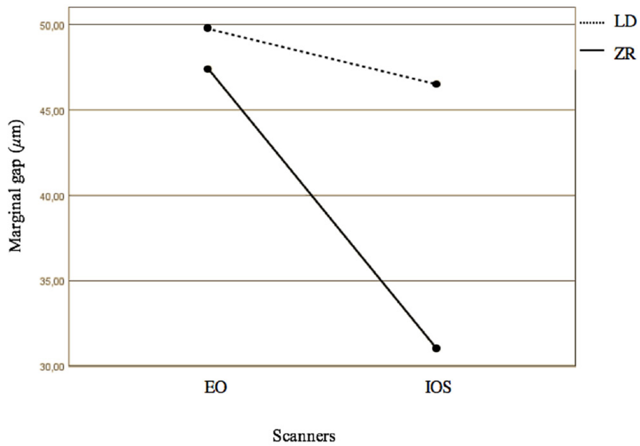

Fig. 3. Interaction between the scanning system and ceramic material (EOS, extraoral scanner; IOS, intraoral scanner) and restoration materials (LM, lithium disilicate monolithic; ZM, zirconia monolithic).

Table 2. Two-way ANOVA results for the marginal discrepancy interaction between groups.

Scanner	SS	df	MS	F	Sig.
Intersection	70,219,372	2	70,219,372	277,425	0,00
Total	11,440,207	40		0	

SS= sum of squares; df= degree of freedom; MS= mean square; F= F-distribution; Sig= significance

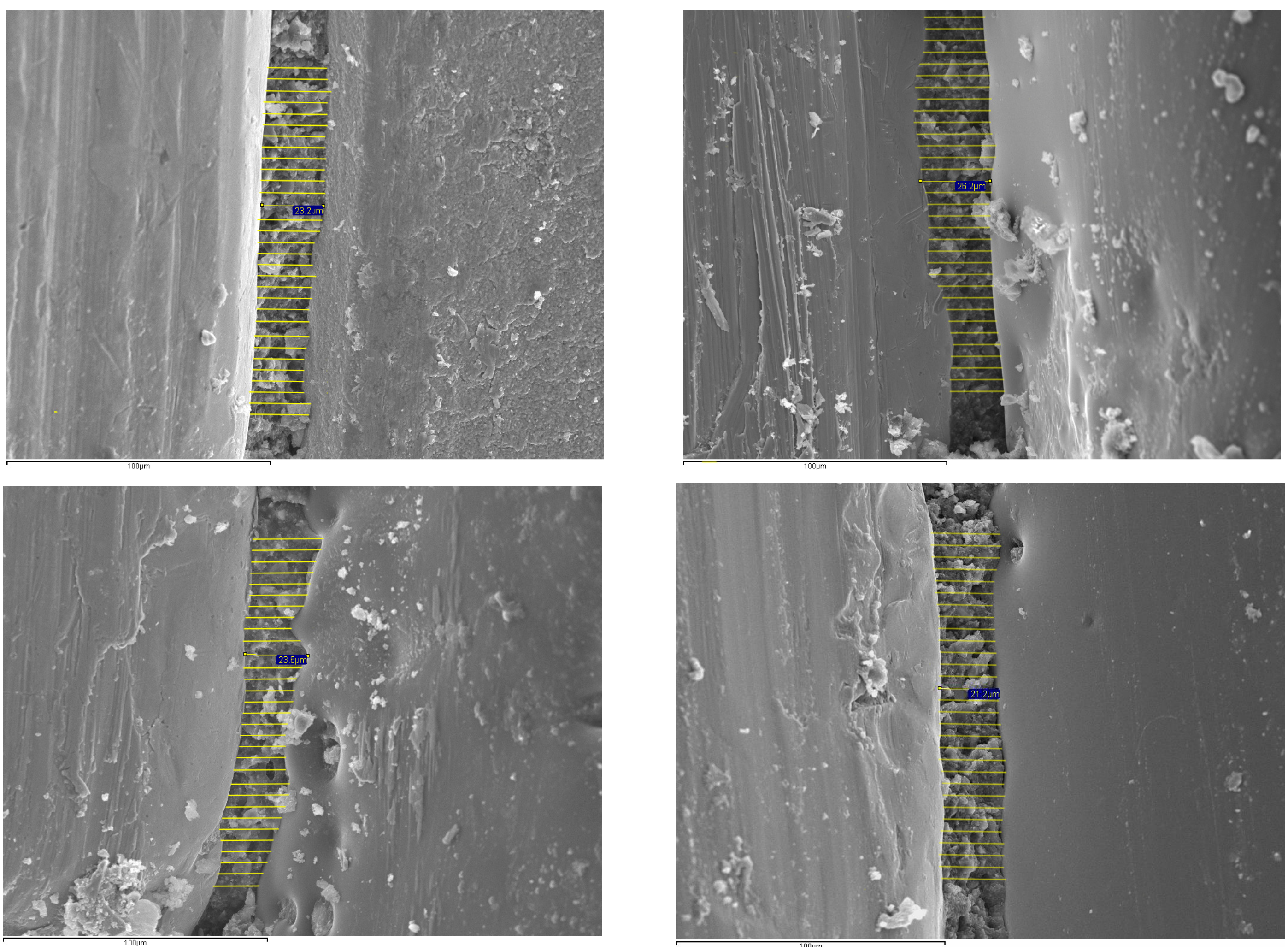

Fig. 4. SEM image (500x), showing the marginal fit: (B) IPS emax CAD specimen (left: IOS, right: EOS).

while, the direct intraoral scanning technique can introduce a certain margin of error [45]. However, when comparing results, it should be noted that most of the studies use the conventional technique of impression taken, model casting and posterior scanning [46-49].

The mean marginal discrepancy obtained in the present study was 41.01 ± 15.38 μm. The mean for each of the groups was 48.58 μm for the EOS, and 35.21 μm for the IOS. Therefore, the results are within different ranges proposed in the literature as clinically acceptable: 100 μm for dental restorations [16,33,35,38,50,51]; 50-100 μm for CAD/CAM restorations [52,53]; and 64-83 μm for single ceramic restoration [11].

The mean marginal discrepancy obtained in the present study was 41.01 ± 15.38 µm. The mean for each of the groups was 48.58 µm for the EOS, and 35.21 µm for the IOS. Therefore, the results are within different ranges proposed in the literature as clinically acceptable: 100 µm for dental restorations [16,33,35,38,50,51]; 50-100 µm for CAD/CAM restorations [52,53]; and 64-83 µm for single ceramic restoration [11].

Overall, the group digitized with the IOS presented lower marginal gap than the group digitized with the EOS. However, when evaluating the marginal discrepancy between the IOS and EOS in each of the ceramic materials, no significant differences were observed. These differences between the results could be related to the sample size. Several previous studies have reported no differences between direct and indirect digitization in terms of marginal fit [26,32,47,49,54]. Nonetheless, in a recent systematic review, it has been reported that for all-ceramic restorations manufactured with CAD-CAM procedure, the direct workflow is a valid alternative to the indirect workflow, showing restorations obtained by means of an IOS better marginal fit than restorations obtained through laboratory scanning [55]. Likewise, several authors have reported lower marginal discrepancies for restorations manufactured by IOS than the obtained by laboratory scans [18,42-44,54,56,57]. Furthermore, Bosniac et al. [43] reported that the method of digitizing a conventional impression using a laboratory scanner seemed to have reached its limits in the clinical environment. In addition, the results for IOSs can be affected positively in in vitro studies due to the ideal conditions that no reproduce the clinical situation [58].

Few studies evaluate the marginal discrepancy between different scanners and different ceramic systems. Duqum et al. [40] did not observe significant differences between two digital workflows in either, lithium disilicate monolithic crowns nor zirconia monolithic crowns. However, Ueda et al. [48] observed lower marginal discrepancy values in cobalt-chromium alloy restorations with the IOS than with the EOS. Most of the studies evaluate different scanners in only a ceramic group. Sakornwimon et al. [49] did not find differences in monolithic zirconia crowns in the different measurement areas between the conventional, and intraoral scanning. On the other hand, other studies that analyze different IOSs and/or different conventional techniques of extraoral digitization, observed that the differences are found according to the groups analyzed [18,47].

The differences observed with previous studies reported in the literature could be due to the different methodologies used. The absence of a standardized methodology among the different authors is one of the main problems when comparing the results [3,33,36,37]. Although several protocols have been proposed to evaluate the marginal discrepancy, there is no guide to unify the measurement of the marginal gap [33,36,59]. The present study used the technique of direct evaluation through a SEM, which allows position the restorations in a base to obtain standardized measurements [3,36]. Other authors [46,48,49] use the replica-technique, a non-invasive and non-destructive method [32,46] that allows determining the marginal adaptation in both in vitro and in vivo studies [46]. However, unlike direct measurement, replica technique only allows measurements of marginal discrepancy in limited locations [49]. Another difference when comparing the results can be the presence or not of cement during the measurement, since the marginal mismatch increases after cementation [28]. However, in the present study it was decided to perform measurements with the crowns cemented because to reflect the clinical conditions [3,37,60]. In the study, 50 µm of space cement was selected for the interposition of an even layer of cement [13], and previous studies reported marginal fit values within clinically acceptable limits with the same cement space [3,33,36,61].

The present study presents a number of limitations. The first limitation is located in the study design. As it was an in vitro study, in which devices have been introduced to make the results more standardized, it makes that the conditions in which the study has been developed do not simulate clinical reality. Likewise, pretreatment of the crowns previous to cementation or adjustments have been avoided to standardize the procedure. Therefore, these results should be interpreted with caution, and later confirmed with in vivo studies. Furthermore, since only the marginal discrepancy in a single tooth was evaluated in the present study, it is not assessed whether in other situations such as in the case of fixed partial dentures, the marginal discrepancy of the different scanners could change, so that a study analyzing this situation could be carried out in the future.

5. Conclusion

Having regard to the limitations of this in vitro study, the CAD/CAM monolithic ceramic crowns manufactured with the intraoral scanner presented the best marginal discrepancy. Nevertheless, when analyzing the marginal discrepancy in each of the ceramic systems analyzed, no differences were observed between the scanners.

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Conflict of interest statement

The authors reported no conflicts of interest related to this study.

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