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Research

Evaluation of Diverse Digital Impression Systems on the Three-Dimensional (3D) Fit of All-Ceram CAD/CAM Crowns

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Abstract

Aim: This in vitro study's objective is to assess the Three-Dimensional (3D) internal and marginal fit of all-ceramic CAD/CAD crowns produced by various digital impression systems.

Materials and Methods: Three different intraoral scanners: CEREC Primescan (Dentsply Sirona), Trios 4 (3Shape), and CS 3700 (Carestream Dental) were used to digitally scan an experimental model based on ISO 12836:2015. The CAD/CAM processes suggested by each system (CEREC Primescan, Trios 4 and CS 3700; N = 15) were used to create ceramic crowns. A 3D inspection program (Geomagic control X) was used to measure The Three-Dimensional (3D) marginal and internal fit of each ceramic crown. By using the Kruskal-Wallis test, differences between the systems and various measurements were assessed. Pairwise comparisons were used to validate statistically significant differences (= 0.05).

Results: Occlusal gaps in the CEREC Primescan, Trios 4 and CS 3700 groups were 113.0, 161.3, and 438.2 µm, respectively ($p<0.001$). The axial gaps were 83.4, 78.0, and 107.9 µm, respectively. While the marginal gaps were 77.8, 99.3, and 60.6 µm, respectively, finally the whole gaps were 85.9, 107.3, and 214.0 µm, respectively. The marginal gap sizes with the Trios 4 system were considerably different from those with the other two systems. The CEREC Primescan system proved no distinctive variations between the four measured regions. However, the Trios 4 and CS 3700 systems did show a statistically significant difference ($p<0.05$).

Conclusion: The marginal gap, which is the most essential aspect in the marginal and internal fit of fixed prostheses, was recorded to be below 100 µm in all three systems, leading to the conclusion that all three systems are capable of producing clinically acceptable prostheses.

***Keywords:** Three-Dimensional (3D); Marginal and internal fit; All-Ceram CAD/CAM; CEREC Primescan; Trios 4; CS 3700.*

Introduction

Over the past few decades, the popularity of all-ceramic restorations has risen sharply due to the increasing esthetic demand. Practitioners, dental technicians and manufacturers are working together to meet this demand. The resulting technological advances have led to new methods of data acquisition and production in the prosthetic field.

Although conventional crown fabrication has proven to be reliable, each step in the process has the potential to decrease the proper fit of the prosthetic part (1). With the introduction of digital technology, it is possible to reduce these steps to three, which are the optical impression, the virtual design of the prosthesis, and the manufacturing part. It corresponds to the English term generally used CAD/CAM (computer-aided design/computer-aided manufacturing). These new procedures are also more comfortable for the patient and, in the case of immediate manufacturing of the final restoration, the provisional stage is dispensed (2).

All-ceramic crowns have superior optical qualities and improved biocompatibility compared to metal-ceramic crowns (3), but one of the most important criteria for prosthetic success is the quality of the marginal fit (4).

Clinically it is possible to evaluate this adaptation with a probe, but the discriminating power of this tool is very low. An in vitro study with acquisition of 3D and 2D images that can be analyzed is scientifically more appropriate to give an opinion on these new technologies (4).

Many studies have investigated several commercially available intraoral scanners and the marginal fit of prostheses fabricated with CAD/CAM systems (5-12). However, few studies have examined the Three-Dimensional fit of crowns made with CAD/CAM systems to assess different scanner types.

Therefore, the aim of the present study of is to compare three of the most recent digital impression systems on the market: CEREC Primescan (Dentsply Sirona), Trios 4 (3Shape) and CS 3700 (Carestream Dental), by assessing the marginal and internal fit of their All-Ceram CAD/CAM crowns.

The null hypothesis assumes that there would be no difference in the Three-Dimensional fit of All-Ceram CAD/CAM crowns from the three types of digital impressions systems studied.

Materials and Methods

Design and manufacture of a master model

Power analysis software (G*Power v.3.1.9.2) was used to calculate the sample size, which was determined to be 15 per group (true power = 96.2%; power = 94% = 0.05) in a pilot experiment that was run five times using the same procedures as the current study. According to this finding, at least 15 samples from each group were required for our study to have >96.2% power.

An experimental model based on ISO 12836:2015 was used since there isn't an existing experimental model for CAD/CAM workflows. In this regard, he was applied using computer-aided design software (SolidWorks Pro 2015). And for the current study, a ceramic crown preparation for a right maxillary second molar was designed as follows: a cylinder (diameter: 7.5 mm, height: 7.5 mm) was formed, subsequently an angle of a total convergence of 12° was established. Then a slot with a depth and width of 0.5 mm was created on the occlusal surface of the cylinder. Finally, the preparation margin was determined by a 1.5 mm fillet.

After the master model was designed, it was manufactured using computer-aided manufacturing equipment (RXP200DS; Röders GmbH). Polyetheretherketone (PEEK) (Pekkton; Cendres+Métaux), the material of choice, was used because of its excellent physical condition.

Fabrication and digital impression of study models

On the basis of the master model, 15 study models per group were made. First, a custom impression tray for taking impressions of the master model was designed with an appropriate shape, with a regular spacing of 2.0 mm assigned to the impression materials. This was achieved using computer-aided design software (SolidWorks Pro 2015). Subsequently, 45 custom impression trays, 15 per group, were fabricated using a 3D printer (Pro 95; SprintRay). A resin (ZMD-1000B; Dentis) was chosen as the 3D impression material.

In order to make the master model impression, the heavy-body impression material (Aquasil Ultra Rigid; Dentsply Sirona) was placed in the custom tray, while the light-body impression material (Aquasil XLV; Dentsply Sirona) was placed around the abutment tooth. All impressions were meticulously examined under a light microscope once the master model was removed to look for any damage or mistakes.

The impression was then filled with Type IV plaster (Fujirock; GC), and the model was removed once the modeling material had dried. Study models were made by repeating the process of making plaster models, and all resulting models were inspected using the same light microscope used to observe the impressions.

Intraoral scanners such as the CEREC Primescan (Dentsply Sirona), Trios 4 (3Shape), and CS 3700 (Carestream Dental) were used to acquire digital impressions of the study models. The models were scanned in accordance with the manufacturer's instructions without the use of any additional scanner settings. Only one skilled user (T. B.) operated each intraoral scanner employed in this study. The scanning strategy was the same for all three intraoral scanners: occlusally, buccally, and lingually of the die. The models included relevant data such as margins, buccal and lingual sides, mesial and distal surfaces, and the triangular structure between the two abutment teeth that were implemented to align the scanned data.

Design and manufacture of ceramic crowns

According to a prior study, when the crown is processed using a CAD/CAM technology, a clinically acceptable marginal space should be less than 100 µm (13). Therefore, in the software of each system, the cement space setting values were determined to allow the manufacturing of crowns with a marginal space < 100 µm. Thus, and based on the pilot experience, the cement space setting value for the CEREC Primescan system (Dentsply Sirona), the Trios 4 system (3Shape) and the CS 3700 system (Carestream Dental) was 100 µm.

Using CEREC software (CEREC SW 5.2), the crown was designed as follows: patient information was entered, then the teeth to be restored, the types of prostheses and the materials to be used were selected (Fig. 1.A). Next, the insertion axes without margins or undercuts were determined (Fig. 1.B). After selecting the crown design from the library (Fig. 1.C), the crown's position and size were adjusted (Fig. 1.D). Next, the setting values for the following input variables were then provided; cement space 100 µm (Fig. 1.E). Finally, the position and dimensions of the crown inside the lithium disilicate ceramic block (IPS e.max CAD LT; Ivoclar Vivadent AG) were checked with the software before the crown was fabricated (Fig. 1.F). The IPS e.max CAD block was processed using a CEREC MC XL milling device (Dentsply Sirona), and the milled crown was crystallized using a Programat P300 ceramic furnace (Ivoclar Vivadent AG) according to the manufacturer's instructions.

Regarding the Trios software (TRIOS Design Studio VR 21.4), the same procedure was applied to create the crown (Fig. 2). From a lithium disilicate ceramic block, the ceramic crown was crafted (IPS e.max CAD LT; Ivoclar Vivadent AG) with a DWX-42W milling device (DGSHAPE). Then it was fired using the same technique as the CEREC system.

Regarding the Carestream software (CS Restore), the crown was designed with all the same input variables, as the two systems discussed above (Fig. 3). Finally, the size of the crown within the block was checked and its location was adjusted (Fig. 3.F). Next, the ceramic crown was fabricated from a lithium disilicate ceramic block (IPS e.max CAD LT; Ivoclar Vivadent AG) using a CS 3000 milling machine (Carestream Dental). Finally, the crystallization process followed the same steps as the two earlier systems.

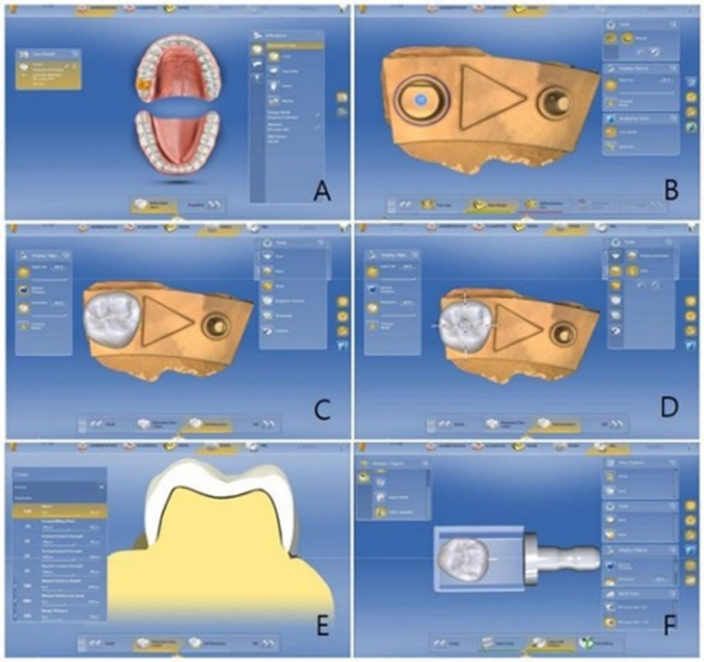

Fig. 1*: Crown design process using computer-aided design and manufacturing software with the CEREC system.*

A*: Definition of a prosthesis (tooth selection, material selection);* ***B****: Margin setting;* ***C****: Design suggestions;* ***D****: Modification of prosthesis design (size, position);* ***E****: Parameter setting;* ***F****: Confirmation of size and position in the block for milling.*

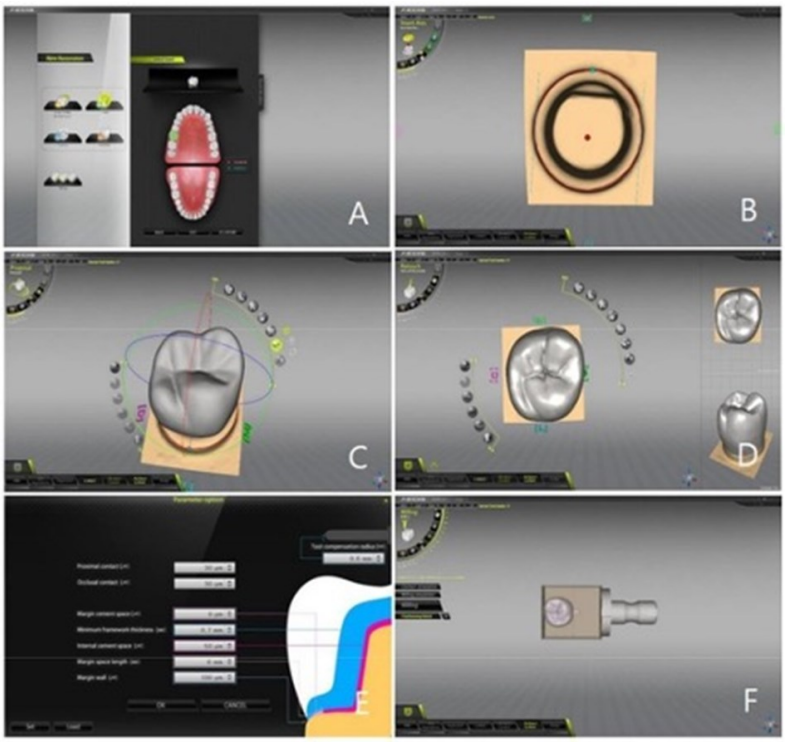

Fig. 2*: Crown design process using computer-aided design and manufacturing software with the Trios system.*

A*: Selection of teeth to be restored;* ***B****: Design of margins and insertion axes;* ***C****: Crown selected from the proposed library;* ***D****: Modeling of the crown;* ***E****: Numerical values as parameters;* ***F****: Alignment of the crown for milling.*

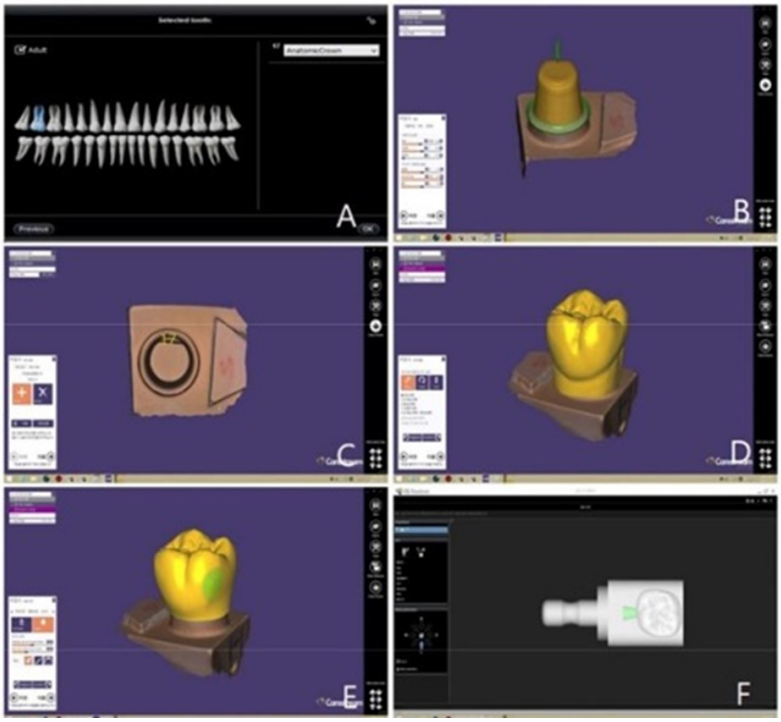

Fig. 3*: Crown design process using computer-aided design and manufacturing software with the Carestream system.*

A*: Selection of teeth to be restored;* ***B****: Numerical values as parameters.* ***C****: Design of margins and insertion axes;* ***D****: Selection of the crown from the proposed library;* ***E****: Modeling of the crown;* ***F****: Alignment of the crown for milling.*

Three-Dimensional (3D) analysis of marginal and internal adaptation

The triple-scan data were collected using the following procedure: the intaglio of the crown was scanned using a DS10 contact scanner (Renishaw plc) and the data were recorded in STL format. The contact scanner employs a probe that gently touches the surface and can move 200 mm up and down. The intaglio of the crown milled with a 1.0 mm bur was accurately scanned with a 0.5 mm diameter probe. The probe was applied to scan from the end of the crown intaglio to the end of the crown margin. On the inner surface of the crown, the probe recorded the coordinates of over 20,000 spots. This method was ideal for scanning the recessed surface of a lithium disilicate crown because it does not result in any errors due to the optical properties of the object. In addition, the accuracy could be accurately analyzed due to the excellent repeatability and reproducibility possible with this instrument.

After that, a dental optical scanner (Identica Hybrid; Medit) was used to scan the abutment tooth model, and the data were saved in STL format. Without using any special scanner settings, the models were scanned in accordance with the manufacturer's instructions.

Finally, the crown was installed in the clinically precise location on the abutment tooth of the study model, scanning powder (Snow Scan Powder; DK Mungyo) was sprayed on, and scanning was performed using a dental optical scanner (Identica Hybrid; Medit). Scanning powder was applied in a single, thin, uniform layer.

The relative data obtained were named respectively: "crown intaglio file" (Fig. 4.A), "die file" (Fig. 4.B) and "adaptation file" (Fig. 4.C).

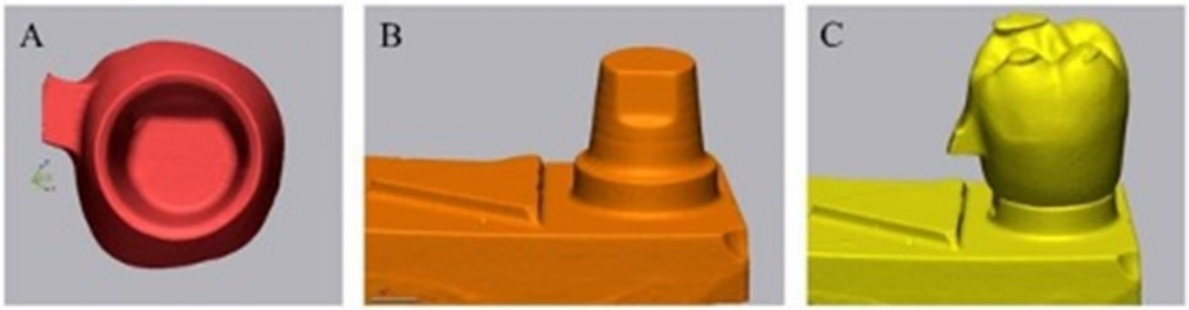

Fig 4: A: *Crown intaglio file;* ***B:*** *Die file;* ***C:*** *Adaptation file.*

The 3D inspection program (Geomagic Control X; 3D Systems) was used to analyze these three files (Fig. 5.A). The superposition of the three files obtained by the triple-scan technique: "crown intaglio file", "die file" and "adaptation file"; was defined as reference data. An initial alignment was conducted, followed by an optimal fit alignment (Fig. 5.B). After the optimal alignment, the adaptation file was deleted, and the die and crown intaglio files were used as reference and measurement data, respectively. Then, the internal and marginal deviations were measured. The die file was detached into the cervical, axial, and occlusal areas in order to do the 3D analysis of each region (Fig. 5.C), while the outer crown surface was removed from the crown intaglio file based on the cervical boundary (Fig. 5.D). The 3D analysis was performed with the entire inner surface of the crown (Fig. 5.E), as well as in each region of the inner surface: cervical (Fig. 5.F), axial (Fig. 5.G) and occlusal (Fig. 5.H).

A root mean square (RMS) value was used to represent the variation between the reference and the measured data. A higher RMS value means a larger error (i.e. a larger difference between the reference data and the measured data). Using the following equation, the RMS value was determined.

$$RMS = \frac{1}{n} \sum (x_{1,i} - x_{2,i})^2$$

Where X1, i is the measurement point in k in the reference data, X2,i is the measurement point in k in the measured data, and n is the total number of measurement points per specimen.

Statistics

All measured data were analyzed using statistical software (IBM SPSS Statistics v23.0; IBM Corp) (= 0.05). First, the Shapiro-Wilk test was used to determine whether the data had a normal distribution, and it revealed that they did not.

Non-parametric statistical techniques were applied since the data were not normally distributed. The Kruskal-Wallis test and a pairwise comparison were used as post hoc tests (= 0.05) to assess differences across systems and measured areas.

Results

Figures 6 and 7 illustrate the occlusal, axial, cervical and whole gaps in the three systems studied: CEREC Primescan (Dentsply Sirona), Trios 4 (3Shape) and CS 3700 (Carestream Dental).

The occlusal space was smallest in the CEREC Primescan system (113.0 µm), followed by the Trios 4 system (161.3 µm) and the CS 3700 system (438.2 µm); ($p<0.001$), (Fig. 6.A). The axial deviation was smallest in the Trios 4 system (78.0 µm), followed by the CEREC Primescan system (83.4 µm) and the CS 3700 system (107.9 µm); ($p<0.001$), (Fig. 6.B). The marginal deviation in the CS 3700 system had the least value (60.6 µm), followed by the CEREC Primescan system (77.8 µm) and the Trios 4 system (99.3 µm); ($p<0.001$), (Fig. 6.C). The total deviation was small in order: the CEREC Primescan system (85.9 µm), the Trios 4 system (107.3 µm) and CS 3700 (214.0 µm); ($p<0.001$), (Fig. 6.D).

In addition, we evaluated the significance of each item: occlusal, axial, cervical and total deviations, such that $p<0.001$ without the CEREC group. Indeed, the CEREC Prime scan system showed no statistically significant difference between the four measured regions ($p = 0.514$), (Fig. 7.A). The Trios 4 system showed a statistically significant difference between the occlusal space and the spaces of the other three regions: axial, cervical and total ($p<0.001$), (Fig. 7.B). Statistically significant differences were also found between the occlusal space and two other measured locations: the axial space as well as the marginal space in the CS 3700 system ($p<0.001$), (Fig. 7.C).

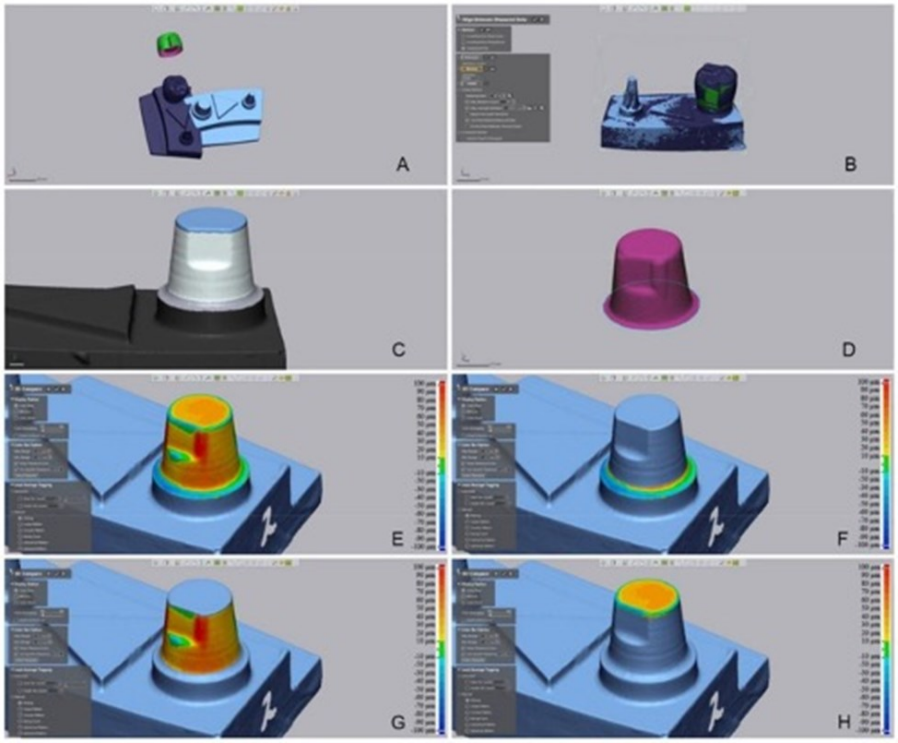

Fig. 5: *Measurement of marginal and internal fit using triple-scan data.*

A: *Import of three scan files;* ***B:*** *Initial alignment and best fit;* ***C:*** *Segmentation of the measurement region;* ***D:*** *Removal of crown data beyond the margin;* ***E:*** *Measurement of overall internal space;* ***F:*** *Three-Dimensional comparison in the cervical section;* ***G:*** *Three-Dimensional comparison in the axial section;* ***H:*** *Three-Dimensional comparison in the occlusal section.*

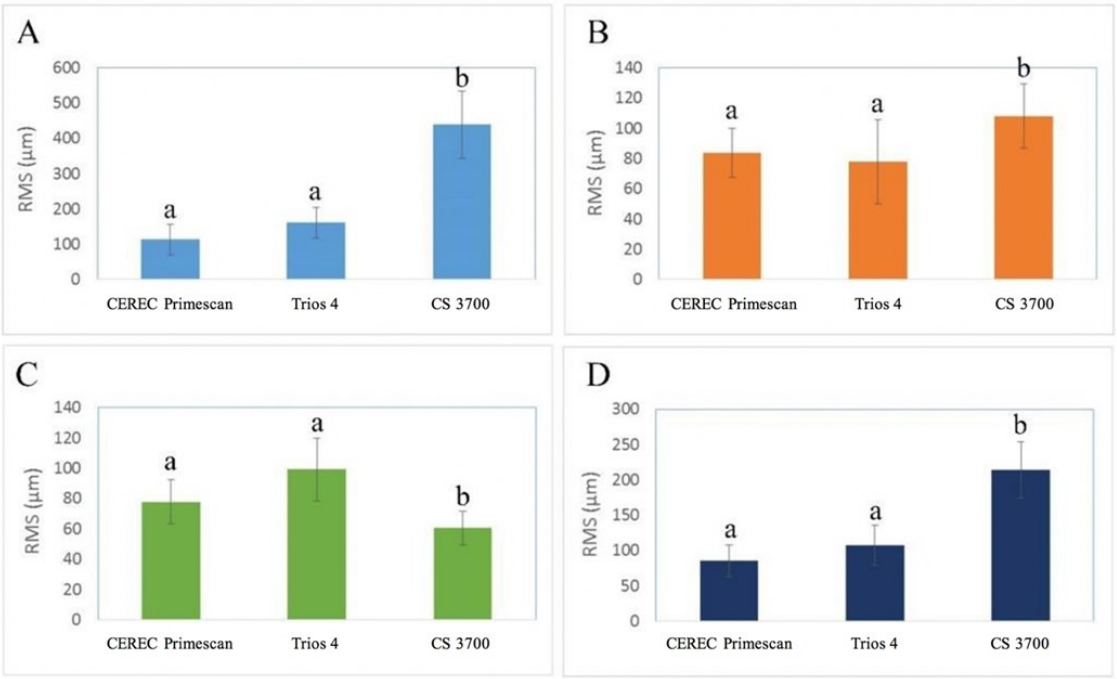

Fig. 6*: Comparisons of marginal and internal fit in each measurement region.*

A*: Occlusal deviation;* ***B****: Axial deviation;* ***C****: Marginal deviation;* ***D****: Total deviation. Values with the same letter (a, b) are not statistically different based on a pairwise comparison test (p<0.05).*

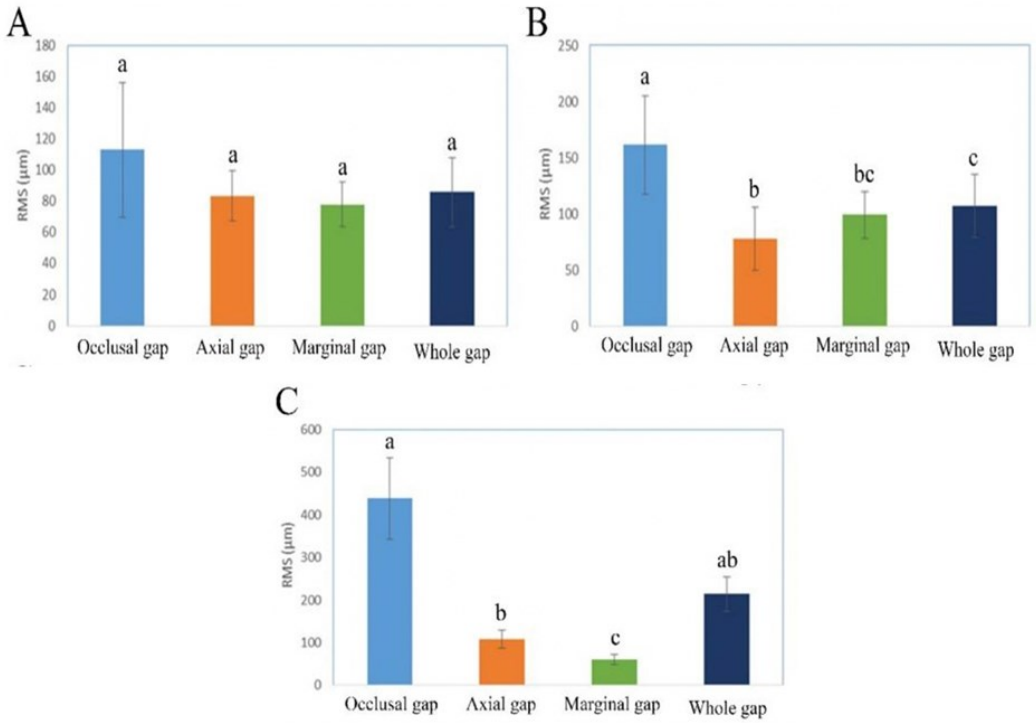

Fig. 7: *Comparison of marginal and internal adjustments within each group.*

A: *CEREC Prime scan system;* ***B:*** *Trios 4 system;* ***C:*** *Carestream system. Values with the same letter (a, b, c) are not statistically different based on a pairwise comparison test (p<0.05).*

Discussion

The null hypothesis that there is no difference in the Three-Dimensional fit of All-Ceram CAD/CAM crowns from the three types of digital impression systems studied was rejected. CEREC Primescan (Dentsply Sirona), Trios 4 (3Shape) and CS 3700 (Carestream Dental) showed statistically significant differences in the marginal and internal fit of the All-Ceram CAD/CAM crowns, but these differences were still clinically acceptable.

The following factors may influence the marginal and internal fit of ceramic crowns obtained with CAD/CAM systems: prosthesis type (14, 15), fabrication materials (16,17), abutment tooth design (18), scanner accuracy (19,20), design software (21), assigned input variables (22), and processing equipment accuracy (23).

The Three-Dimensional fit of All-Ceram CAD/CAM crowns in this experiment may have been affected by the scanners' accuracy, the design software's functionality, the assigned input variables, and the accuracy of the processing equipment.

Starting with the different acquisition modes of the optical scanners; indeed, the CEREC Prime scan and Trios 4 systems adopt confocal microscopy (24, 25), while the CS 3700 system uses active flow projection triangulation (26).

Likewise, plaster teeth were scanned in this study and thus the scanners may not have produced scans as accurate as those potentially possible on human teeth. The differences in depth and scattering produced by the two optical systems may have stronger clinical implications and differences when used in vivo, with human hard and soft tissue scanned (27,28).

Ercoli, et al. (29) reported a marginal space of 120 µm in a crown made using a CAD/CAM system, as they suggested that this discrepancy may be caused by the transformation of the digital model into a prosthesis. Albayrak, et al. (30) reported that a ceramic crown (IPS e.max CAD; Ivoclar Vivadent AG) had a marginal space between 74 and 76 µm, which falls within a clinically acceptable range.

Prior to the main experiment in this study, the proper cementing space for each system was established. Marginal and internal fit were assessed without comprehensive descriptions of the input variables in numerous prior studies of prostheses made with CAD/CAM systems. Like cast prostheses, whose accuracy depends on the skill of the practitioner and the materials, CAD/CAM prostheses yield different results due to: differences in optimization between the equipment and software; the condition of the tools (scanner tip and bur); compensation; and the skill of a practitioner. So that the experiment could be repeated, the current study sought to identify the best input variables for the condition setting step.

It should be noted that the measurement of marginal and internal deviation before cementation provides useful information for evaluating the accuracy of intraoral scans and subsequent crown fabrication. However, the results of this study cannot really be applied to a clinical scenario because cementation would introduce other factors that could influence the marginal and internal fit of All-Ceram CAD/CAM crowns, such as the luting agent (31), as well as the applied seating force (32) are factors that influence the final Three-Dimensional gap.

Finally, the precision of the equipment used to manufacture the All-Ceram CAD/CAM crowns may have influenced their Three-Dimensional adaptation. Indeed, this phase involves grinding the hard lithium disilicate with diamond burs, which could introduce microstructural defects in the crown and the intrados surface. Variations may exist between the specific diamond burs used by each milling system, which may have created inconsistencies in the crown surface, and subsequently impacted the final fit (33). Since various milling units were used in the present study, each combined with the best scanner recommended by the manufacturer. It is worth mentioning that the three milling devices CEREC MC XL (Dentsply Sirona) DWX-42W (DGSHAPE) and CS 3000 (Carestream Dental) all have four grinding axes.

The Three-Dimensional fit of a crown on a tooth consists of a horizontal, vertical and z-axis relationship between the crown margin and the tooth preparation line. In this regard, all digitized data were analyzed using the triple-scan method (34). Prior to the main experiment, a pilot experiment was carried out to validate this 3D measurement, it has also been employed in numerous studies as well (35,36).

The CEREC Primescan system (Dentsply Sirona), had the narrowest occlusal space at 113.0 µm, followed by the Trios 4 system (3Shape) at 161.3 µm. However, the CS 3700 system (Carestream Dental) had a space of 438.2 µm, which was much larger than the occlusal spaces of the other two systems. This could be attributed to the difference in accuracy between the milling equipment and the intraoral scanner. Additional study is required to determine the effectiveness of the Carestream system's newly introduced intraoral scanner and milling unit.

In the present study, the marginal space of a ceramic crown made with three types of CAD/CAM systems was within the clinically acceptable range, as CEREC Primescan (Dentsply Sirona), Trios 4 (3Shape) and the CS 3700 system (Carestream Dental) recorded marginal spaces of less than 100 µm in width. Although the literature suggests a value between 50 and 200 µm, the maximum clinically acceptable marginal gap has not yet been determined. Specifically, the range of 100-120 µm reported by McLean, et al. has often been used (37).

Finally, the present in vitro study had limitations. The scanning process did not accurately represent the clinical setting (wet environment, ambient light, etc.). Therefore, further clinical studies are needed in the future. Additionally, more researches on fixed prostheses for several units are needed.

Conclusion

The different CAD/CAM workflows affected the marginal and internal fits of the ceramic crown. All three systems studied were found to be capable of fabricating clinically acceptable All-Ceram CAD/CAM crowns, as the marginal deviation, which is the most important component of the marginal and internal fit of the prostheses, was recorded as less than 100 µm for each of the three systems.

Within the limitations of this study, advances in scanning technology have produced improvements in the accuracy of crown margins.

Source of Support

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Conflict of Interest

None

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