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RESEARCH AND EDUCATION

Marginal fit of CAD-CAM monolithic zirconia crowns fabricated by using cone beam computed tomography scans

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ABSTRACT

Statement of problem. Information regarding the precision of monolithic zirconia crowns fabricated by using a standard computer-aided design and computer-aided manufacturing (CAD-CAM) workflow is available. However, information on the effect of a modified workflow using 3D laboratory scanning and/or cone beam computed tomography (CBCT) for monolithic zirconia crown fabrication is lacking.

Purpose. The purpose of this in vitro study was to evaluate the effect of different scans on the marginal fit of CAD-CAM monolithic zirconia crowns fabricated by 3D laboratory scanning and CBCT.

Material and methods. An extracted maxillary left first molar was prepared and digitized by using a 3D laboratory scanner (D900; 3Shape A/S) (control group). The tooth was also scanned by CBCT (i-CAT; Imaging Sciences) to generate a second virtual 3D model (CBCTscan group). A tooth cast out of polyurethane (PU) (Zenotec Model; Wieland) was reproduced from the CBCT data by using a CAD software program (Dental System 2.6; 3Shape A/S) and milling machine (CORiTEC 550i; imes-icore) and further scanned by using the 3D laboratory scanner to generate a third virtual 3D model to represent a clinical scenario where a patient's cast is needed (PU3DLab group). A monolithic zirconia crown design (cement space: margin 40 μm, 1 mm above 70 μm) was used on the virtual models, and crowns were fabricated out of presintered zirconia blocks (ZenostarT4; Wieland) by using a 5-axis milling machine (CORiTEC 550i; imes-icore). The crowns were sintered (Sinterofen HT-S Speed; Mihm-Vogt), and the vertical marginal discrepancy (VMD) was measured by ×100-magnification microscopy. Measurements were made at 384 points in 3 groups of 16 specimens. The measurements for each specimen were averaged, and VMD mean values were calculated. The Kruskal-Wallis test was used for the statistical analysis (α=.05). The Mann-Whitney U test and Bonferroni adjustment were further used to compare the pairs (α=.017).

Results. The mean VMD value was 41 μm (median: 38 μm) for the control group, 44 μm (median: 42 μm) for the CBCTscan, and 60 μm (median: 58 μm) for the PU3DLab. No significant difference was found between control and CBCTscan groups (*P*=.274). However, there was a significant difference between control and PU3DLab and CBCTscan and PU3DLab groups (*P*<.001).

Conclusions. Marginal fit of the crowns fabricated by using the 3D laboratory scanner and through the direct use of CBCT was better than that of the crowns fabricated by using the workflow that combined the use of CBCT, PU cast, and 3D laboratory scanner. All tested protocols enabled the fabrication of monolithic zirconia crowns with a marginal discrepancy smaller than 120 μm. (J Prosthet Dent 2020;123:731-7)

Computer-aided design and computer-aided manufacturing (CAD-CAM) technology is now commonly used in restorative and prosthetic dentistry.[1] Obtaining digital data and creating 3D virtual models has become a common procedure for a wide range of prosthetic materials available in the form of prefabricated blocks.[2]

One of the methods of generating a virtual model is by digitizing a gypsum cast by using a laboratory scanner.[3] However, impressions may sometimes cause discomfort for the patient by provoking a gag reflex or pain during gingival displacement.[4] In addition, distortion of the impression may occur because of disinfection

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Clinical Implications

Using the tested protocols including cone beam computed tomography scans for the fabrication of zirconia crowns on molar teeth may be an option for clinicians after occlusion, and the interproximal contact integrity of these crowns is supported by other studies.

protocols and storing until pouring of the gypsum cast.[5,6] Another way to generate a 3D virtual model is by intraoral scanning of the patient.[7] However, intraoral scanners are expensive and not available in all dental practices. Three-dimensional virtual models can also be generated from cone beam computed tomography (CBCT) images converted into standard tessellation language (STL) files by using a CAD software program and used to reproduce and fabricate patient-specific surgical guides for implant placement, implant-supported fixed dental prostheses (FDPs), and solid casts of the dental arches without making conventional impressions.[8,9] Superimposition of the CBCT image files in digital imaging and communications in medicine (DICOM) format and 3D intraoral surface scan files in STL format has been suggested as a reliable procedure[10,11] and is also efficient in terms of cost and time with high patient acceptance.[12,13]

The marginal integrity of FDPs is essential for long-term clinical success.[14-19] Excessive marginal misfit of FDPs may adversely affect the health of the abutment teeth and their periodontal tissue.[14,20-23] Acceptable marginal fit is yet to be defined, but, at the present time, a 5-year clinical study on 1000 restorations has indicated that marginal misfit of FDPs should be less than 120 μm.[24] Some investigators[25,26] have stated that the limit of marginal discrepancy should not exceed 100 μm for CAD-CAM restorations.

Recently, Seker et al[4] reported that clinically acceptable crowns can also be fabricated by CBCT imaging and CAD-CAM. Using this workflow, they fabricated crowns from polymethyl methacrylate (PMMA) with a marginal misfit of less than 120 μm. However, they did not use solid casts in their workflow, and the crowns were not produced from a definitive crown material. Having solid casts can allow the evaluation of interproximal and occlusal contacts of the restoration when fabricated by using intraoral scans.

With the advent of the CAD-CAM technology, high-strength restorations with acceptable esthetics can be fabricated at a reasonable cost and in a reasonable time by using new dental materials such as monolithic zirconia.[15,27-34] Crowns made of monolithic zirconia can withstand loads higher[35] than the average maximal posterior occlusal forces.[36] With their mechanical advantages, monolithic zirconia crowns have become an alternative to conventional metal-ceramic posterior crowns.

Information regarding the precision of monolithic zirconia crowns fabricated by using a standard CAD-CAM workflow is available.[37-39] However, to the best of the authors' knowledge, the effect of a modified workflow using 3D laboratory scanning and/or CBCT on the marginal fit of monolithic zirconia crowns is lacking. The purpose of this in vitro study was to evaluate the effect of different scans obtained from 3D laboratory scanning and CBCT on the marginal fit of CAD-CAM monolithic zirconia crowns. The null hypothesis was that the marginal fit of the zirconia crowns would be similar, regardless of the CAD-CAM workflow tested.

MATERIAL AND METHODS

This study used a human permanent left maxillary first molar with intact hard tissue integrity lost for periodontal reasons. Written informed consent was obtained from the patient before tooth extraction, and ethics committee approval was received for the study (protocol code of approval: 16/06/2016/12). An autopolymerizing acrylic resin material mixed with 4 to 4.5 vol% liquid radiocontrast agent (Iomeron 400; Bracco) was used to make a base to embed the tooth in a vertical position 2 to 3 mm apical to the enamel-cementum junction. The tooth was prepared by an experienced prosthodontist (E.K.) for a complete-coverage ceramic restoration with 1.5-mm occlusal reduction, 1-mm axial reduction, 360-degree 1-mm-deep shoulder margin, and a rounded internal line angle.[40]

A power analysis was conducted by using a statistical software program (GPower 3.1; Heinrich Heine University) to determine the number of specimens (n) needed for at least 80% statistical test power for the study results. Using a recent study[4] with matching material and methods as reference, n was calculated as 15 for $1-\beta=0.80$, with type I error at $\alpha=.05$. The prepared tooth was scanned by using a 3D laboratory scanner (D900; 3Shape A/S), and a CAD software program (Dental System 2.6; 3Shape A/S) was used to design a virtual anatomic-contour crown restoration in STL format with simulated cement space of 40 μm around the margins and 70 μm starting 1 mm occlusal to the finish line (Fig. 1). The designed crown data were used to mill 16 monolithic ceramic crowns by using a 5-axis CAM dental milling device (CORiTEC 550i; imes-icore) from presintered zirconia blocks (Zenostar T4; Wieland). The milled crowns were sintered (Sinterofen HT-S Speed; Mihm-Vogt) at 1150 °C for 12 hours according to the manufacturer's instructions. The crowns fabricated with this CAD-CAM workflow served as the control group (control) (n=16).

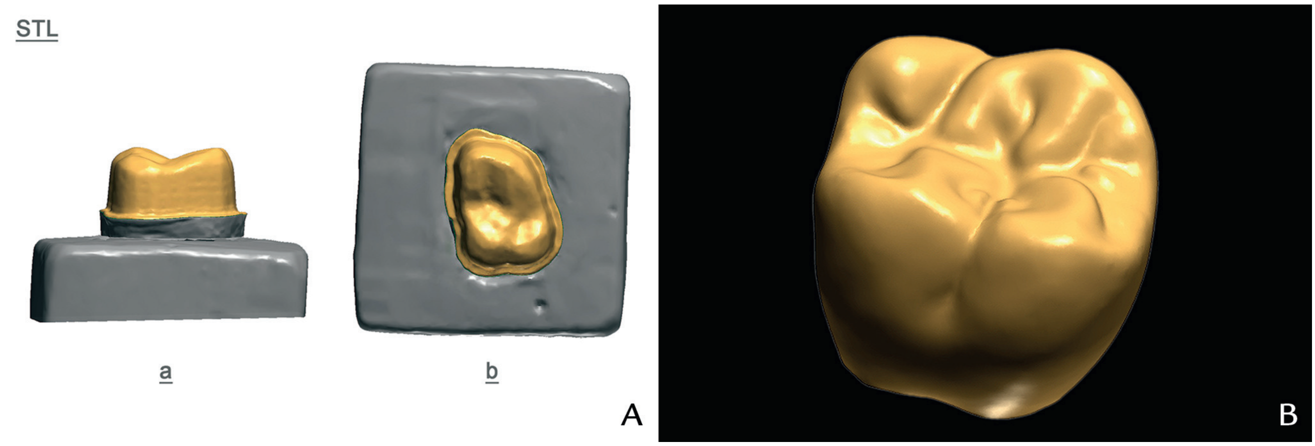

Figure 1. A, STL image of prepared tooth: distal view (a), occlusal view (b). B, Virtual crown design using CAD software. CAD, computer-aided design; STL, standard tessellation language.

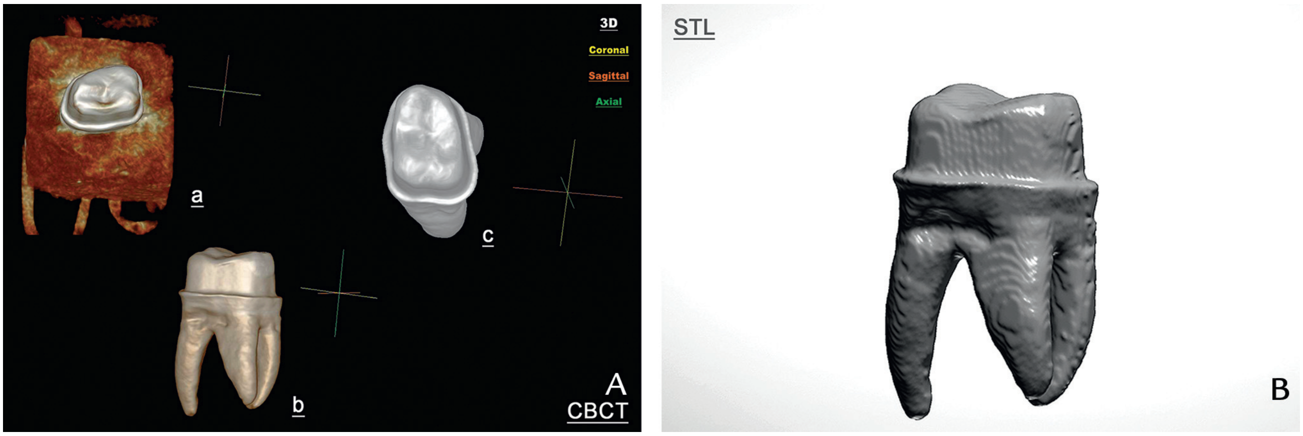

Figure 2. A, 3D CBCT image of prepared tooth: occlusal view of tooth with radiocontrast acrylic resin base (a); distal view of tooth virtually stripped to roots by using CBCT image software (CATVision1.9; Imaging Sciences) (b); occlusal view of tooth with virtually stripped off radiocontrast acrylic resin base (c). B, Image of CBCT-scanned prepared tooth without acrylic resin base in STL file format on CAD software. CBCT, cone beam computed tomography; CAD, computer-aided design; STL, standard tessellation language.

The prepared tooth was also scanned by using CBCT (i-CAT; Imaging Sciences) at "high-quality image" setting, with an 80×50-mm medium field of view (FOV) and a 0.20-mm voxel resolution, and the scanned data (DICOM) were transported to the CAD software program in STL file format (Fig. 2).[4] The same crown design parameters were adapted to the STL image, and another 16 monolithic zirconia crowns were fabricated by using the same sequence of CAM production and sintering. The crowns fabricated with this modified CAD-CAM workflow constituted the first experimental group (CBCTscan) (n=16). The STL image was also processed by using the CAM software program and milling machine to reproduce a polyurethane (PU) cast of the prepared tooth by using a solid block (Zenotec Model; Wieland) to represent a clinical scenario where a patient's cast is needed (Fig. 3). The PU tooth cast was further scanned by using the 3D laboratory scanner, and the same virtual crown design parameters were used to fabricate another 16 monolithic zirconia crowns by using the same CAM and sintering procedures (Fig. 4). The crowns fabricated with this further modified CAD-CAM production workflow constituted the second experimental group (PU3DLab) (n=16).

A permanent marking pen (Multimark 1523S-Blue; Faber-Castell) was used to mark 8 consecutive locations (buccal, mesiobuccal, mesial, mesiopalatal, palatal, distopalatal, distal, and distobuccal) on the intact aspect of the marginal finish line of the prepared tooth.[4] A thin line of ink blot was removed from the marked locations with a single vertical slash by using a surgical blade (Sterile Surgical Blade No: 11; Beybi) (Fig. 5). The crowns were individually fitted onto the prepared tooth, and the marginal integrity at the crown-tooth junction was evaluated circumferentially by using a ×3.5 to ×180 zoom stereomicroscope (SM-3TZZ-54S-10M; AmScope) equipped with a 10-MP digital camera (MU1000; AmScope) and light-emitting diode ring light (LED-54S;

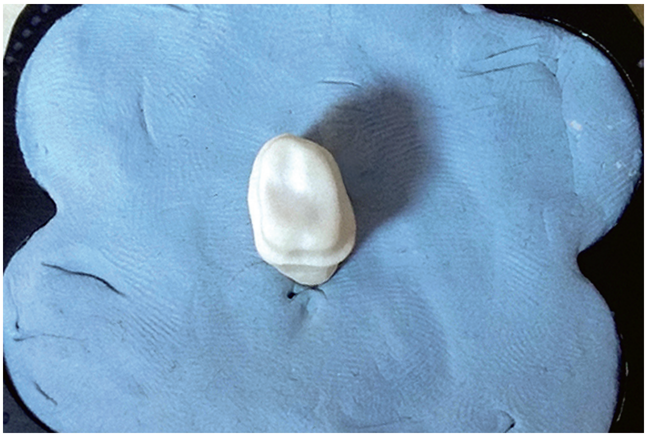

Figure 3. CAD-CAM–fabricated real-size cast of prepared tooth made of PU by using STL image of CBCT-scanned tooth without acrylic resin base (polyurethane cast fixed with silicone impression material before 3D laboratory scanning). CBCT, cone beam computed tomography; CAD-CAM, computer-aided design and computer-aided manufacturing.

Figure 4. Anatomic-contour monolithic zirconia crown fitted on prepared tooth.

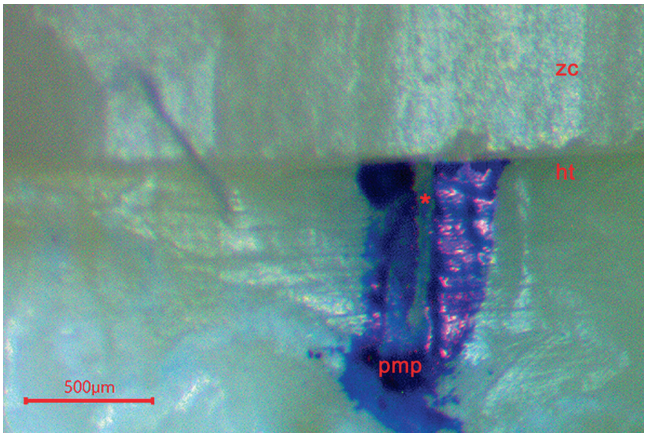

Figure 5. Standardized measurement point on prepared tooth (original magnification ×130). *Asterisk*: area with removed ink due to surgical blade slash (scratch). zc, zirconia crown; ht, human tooth; pmp, permanent marking pen (ink).

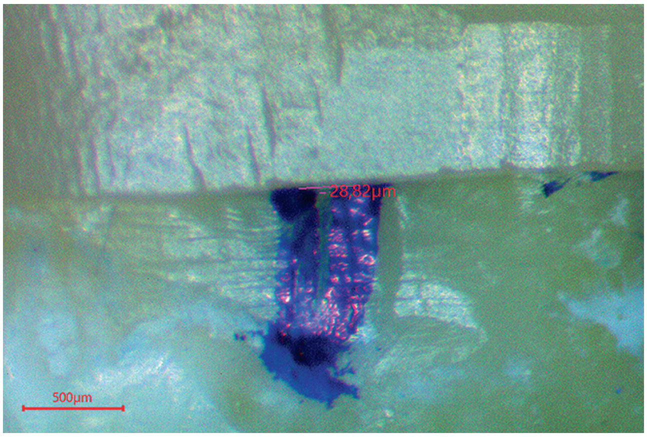

Figure 6. Vertical marginal discrepancy measurement (original magnification ×100).

AmScope).[38,39] Calibration of the camera was performed by using a single calibration slide (MR100; AmScope) with a precision stage micrometer (0.01 mm).[38,39] The crown-tooth junction of each specimen was aligned perpendicular to the evaluation sight of the microscope and monitored.[38,39] The misfit at each of the standardized measurement points of a corresponding crown was determined in terms of vertical marginal discrepancy (VMD), measuring the shortest distance between the virtually drawn line at the crown margin and the parallel line at the tooth finish line in a blade-marked location (Fig. 6).[38,39] The measurements were performed in real time with 3584×2748 resolution on a live-video-stream computer image at ×100 magnification by using a software program (AmScope x86, v3.7.3980; AmScope).[38,39] All measurements were performed by a single operator (M.C.).

A total of 384 measurements were performed on 48 specimens with 8 measurement points in 3 groups (control, CBCTscan, PU3DLab) (n=16/group) of monolithic zirconia crowns fabricated by using different workflows of CAD-CAM production. An average of 8 measurements in each specimen was used as the circumferential VMD value for the corresponding crown. The mean VMD values and standard deviations were calculated for the groups, and the results were analyzed by using a statistical software program (IBM SPSS Statistics, v23.0; IBM Corp). A condition of normally distributed within-group data and homoscedasticity could not be achieved. The Kruskal-Wallis test was used to investigate the statistical difference between groups (α=.05). The Mann-Whitney U test and Bonferroni adjustment were further used to compare group pairs (α=.017).

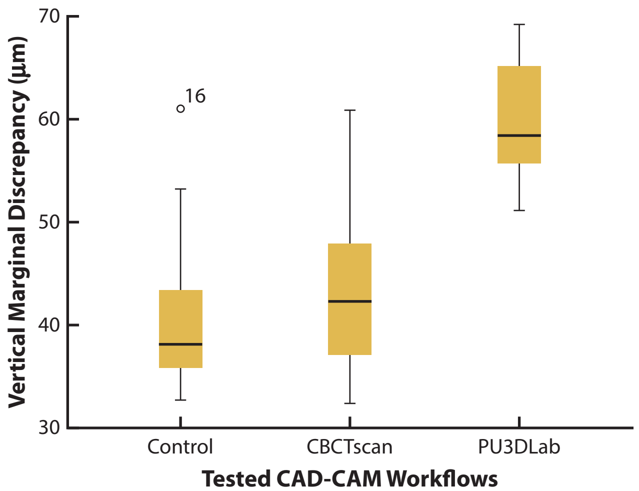

Figure 7. Vertical marginal discrepancy of groups with different CAD-CAM production workflows. CAD-CAM, computer-aided design and computer-aided manufacturing.

Table 1. Kruskal-Wallis results of marginal fit evaluation for different CAD-CAM production workflows

Group	n	Mean Rank	*df*	χ^2	*P*
Control	16	15.44	2	25.478	<.001
CBCTscan	16	19.31			
PU3DLab	16	38.75			

Table 2. Mann-Whitney U test results of marginal fit evaluation for different CAD-CAM production workflows (in view of Bonferroni adjustment)

Group	n	Mean Rank	Sum of Ranks	*U*	*P*
Control	16	14.69	235.00	99	.274
CBCTscan		18.31	293.00		
Control	16	9.25	148.00	12	<.001
PU3DLab		23.75	380.00		
CBCTscan	16	9.50	152.00	16	<.001
PU3DLab		23.50	376.00		

RESULTS

The mean VMD value was 41 μm (median: 38 μm) for control, 44 μm (median: 42 μm) for CBCTscan, and 60 μm (median: 58 μm) for PU3DLab (Fig. 7). The results of the Kruskal-Wallis analysis indicated that different CAD-CAM workflows for monolithic zirconia crowns significantly affected the mean ranks of VMD values for the restorations (Table 1). The Mann-Whitney U test and Bonferroni adjustment revealed statistical difference between groups control and PU3DLab and CBCTscan and PU3DLab (P<.001), whereas no statistical difference was found between groups control and CBCTscan (P=.274) (Table 2).

None of the individual VMD values at the standardized measurement points in group control was measured at or above 120 μm. In group CBCTscan, 3 of the individual VMD values exceeded that threshold, of which the highest was 142 μm, and 4 of the individual VMD values in group PU3DLab, with the highest being 129 μm. A total of 15 individual VMD values were equal to or greater than 100 μm, in 11 different specimens from group CBCTscan and PU3DLab, except group control.

DISCUSSION

The results of this present study revealed that differences in CAD-CAM workflow significantly affected the marginal fit of monolithic zirconia crowns; thus, the null hypothesis was rejected. The groups control (41 μm) and CBCTscan (44 μm) presented with improved precision of fit, with no statistical differences for the mean VMDs in between. The lowest precision of fit was calculated for group PU3DLab (60 μm), with significantly higher mean VMD than groups control and CBCTscan. These results are in accordance with 2 recent studies[38,39] that used similar methods of investigation in which monolithic zirconia crowns were fabricated by using a 3D laboratory scanner and a CAD-CAM system of the same brand and model. The VMD mean value for finished noncemented monolithic zirconia crowns was 38 μm in one and 53 μm in the other.[38,39] In the study[39] with 38 μm of mean VMD, none of the individually measured values exceeded 120 μm as in the group control of the present study. In the study by Kale et al[38] with 53 μm of mean VMD, 5% of the individually measured values exceeded 100 μm, and only 2.5% exceeded 120 μm. This was similar to group CBCTscan with 6.2% individually measured values exceeding 100 μm and 2.3% individually measured values exceeding 120 μm and the group PU3DLab with 5.5% individually measured values exceeding 100 μm and 3.1% individually measured values exceeding 120 μm in the present study. According to these results, both fabrication protocols based on CBCT data (modified workflows) tested in this study may be considered comparable with that of the CAD-CAM fabrication method based solely on 3D laboratory scanning (a standard workflow). These results should be corroborated with clinical studies.

The VMDs calculated in present study were lower than those reported by Seker et al.[4] In that study, 126 μm of mean VMD value was found for their PMMA crowns fabricated with a similar modified workflow and using CAD-CAM and CBCT devices of the same brand and model with the same scanning parameters as in the group CBCTscan. Seker et al[4] used silicone impression material to temporarily fix the specimens on the abutment tooth before inspection of the marginal integrity. Using low-viscosity silicone for interim fixation of crowns has been reported to simulate clinical cementation.[41] Evidence suggests that any film thickness formed by luting cement between crowns and their respective abutments will result in increased VMD.[42] A water-based luting cement has been reported to increase the mean VMD of monolithic zirconia crowns with simulated cement space of 50 μm by approximately 22 μm.[39] If that value was to be added to each of the mean VMD values of the evaluated groups (control, CBCTscan, PU3DLab) in this study, all the VMD values in the groups would still have been smaller than 100 μm.

Ninety-three percent of the peak values measured at the standardized measurement points in this study were associated with the distal aspect of the restoration margin, and 60% were directly related to the distal measurement point of the crowns fabricated with the modified production workflows tested. This result might reflect possible distortion of the distal region of the prepared tooth during CBCT scanning, creating faulty virtual 3D models and therefore crown designs in the experimental groups (CBCTscan, PU3DLab). CBCT scanning parameters may have a significant influence on the accuracy of the virtual models.[43,44] Smaller FOV adjustments may provide better accuracy because of more acute beam angulations in the lower and upper volume areas and increased contrast-to-noise ratio.[44] Voxel size also has an influence on accuracy affecting the spatial resolution of orthogonal slices: the smaller the voxel size, the better the accuracy.[43] Seker et al[4] reported that voxel size had a significant effect on the marginal integrity of CAD-CAM–fabricated crowns on virtual 3D tooth models generated from CBCT scans. Therefore, it is essential to know the scanning parameters to be used to provide optimized results suitable for diagnostics, treatment planning, and rehabilitation, balancing benefits against the risks of ionizing radiation exposure. Further research is needed to investigate the influence of all coexisting parameters on the reconstruction accuracy of virtual casts.

Patients with metal restorations may not be suitable candidates for the production methods in the present study. Existing metal in the volume area at the time of scanning may cause artifacts in the CBCT images, which may alter the accuracy of the reconstruction.[45] The inability to capture soft tissues is also a limitation of this technique. A reduction in the number of appointments and in the clinical cost is the main advantage.

How occlusion would be affected by restorations fabricated by using the modified workflows tested in this study, which did not include printed casts, is not clear. When printed casts of entire arches are available, occlusal and interproximal contact adjustments would be possible. However, in the present study, the prepared tooth was not scanned in occlusion with an opposing dentition, and there were no adjacent teeth for potential proximal contacts. The results may be different in clinical conditions as some of the controlled variables in this in vitro study may be in effect. These matters should be addressed in future studies.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. CAD-CAM fabrication based solely on 3D laboratory or CBCT scanning provided similar and better fit for monolithic zirconia crowns than the workflow which combined CBCT scanning, cast milling, and cast scanning.
2. The workflows based on CBCT data (modified workflows) enabled fabrication of monolithic zirconia crowns with vertical margin discrepancies smaller than 120 μm.

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