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RESEARCH AND EDUCATION

Suitability of the triple-scan method with a dental laboratory scanner to assess the 3D adaptation of zirconia crowns

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ABSTRACT

Statement of problem. The triple-scan method for assessing the 3D adaptation of dental restorations has been introduced and reported to be reliable. However, the suitability of using a dental laboratory scanner in the triple-scan method has not been evaluated.

Purpose. The purpose of this in vitro study was to evaluate the suitability of the triple-scan method using a dental laboratory scanner to assess the 3D adaptation zirconia crowns.

Material and methods. A zirconia abutment and a zirconia crown were fabricated, and the abutment was fixed in a custom-made base. The crown was seated onto the abutment with the interposition of light-body silicone impression material between them. The triple-scan method was performed by using a dental laboratory scanner, and the mean cement-gap thickness was calculated. The seating and digitalization process was repeated 10 times, and after each digitalization, the light-body silicone layer was stabilized by applying heavy-body silicone impression material over it. Cement-gap thickness was measured on cross-sections of the aligned scan data sets and of the physical silicone replica. The results were assessed by using the paired *t* test and the Bland-Altman method (α=.05).

Results. Mean 3D cement-gap thickness assessed by the triple-scan method reported small dispersion with a coefficient of variation of 5.6% for the occlusal area, 1.9% for the axial area, and 6.4% for the margin area. Cement gap thickness measured at corresponding locations in the aligned scan data sets and in the physical silicone replica reported no significant difference (P=.326) and good agreement.

Conclusions. The cement gap was accurately duplicated in scan data sets. The triple-scan method by using a dental laboratory scanner is suitable for assessing the 3D adaptation of zirconia crowns. (J Prosthet Dent 2021;125:651-6)

Internal and marginal adaptation of a dental restoration to its abutment is essential for long-term clinical success. A poor marginal adaptation increases the risk of microleakage, plaque retention, gingival inflammation, and secondary caries.[1-3] Moreover, an inhomogeneous or excessive internal gap will compromise the fracture resistance of restorations.[4,5]

Various methods have been developed to evaluate the adaptation of restorations. Directly observing the marginal gap under a microscope[6] or making measurements on cross-sections after sectioning the cemented restoration[7] has a long history of use. Microcomputed tomography (μCT)

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Clinical Implications

The triple-scan method by using a dental laboratory scanner can be applied to assess the 3D adaptation of zirconia restorations. The present study describes a detailed workflow of data acquisition and processing to provide references for its application.

can be used for 3D adaptation evaluation, but when the restoration is made of a radiopaque material such as zirconia, a special radiopaque fit-testing material is required.[8,9] The silicone replica method,[10,11] in which the gap between restoration and abutment is replicated by using silicone impression material and then measured, has been well received because it is convenient and nondestructive. Besides, 3D measurements can be made by scanning the abutment with and without the silicone replica.[10] However, the silicone replica may need to be repeated to obtain an undamaged replica, required for an accurate measurement.[12]

Recently, Holst et al[12,13] described a triple-scan protocol for the 3D adaptation assessment of dental restorations. The restoration, the abutment, and their assembly are digitized and aligned for analysis. The method has been found to have good repeatability[14,15] if an industrial scanner of high accuracy and with a particular measurement frame is used.[12-16] However, such equipment is not common in dentistry, limiting the use of the triple-scan method.

The data acquisition ability of dental laboratory scanners has been improved[17,18] with the development and application of computer-aided design and computer-aided manufacturing technology in dental practice. The purpose of this in vitro study was to evaluate the suitability of the triple-scan method using a dental laboratory scanner for the 3D adaptation assessment of zirconia crowns. Cement-gap thickness was measured on corresponding cross-sections of aligned scan data sets and of physical silicone replicas. The null hypothesis was that no differences would be found among them.

MATERIAL AND METHODS

A zirconia abutment of the right maxillary first molar with an occlusal reduction of 1.0 to 1.5 mm and a 0.5-mm-wide chamfer was fabricated and scanned with an intraoral scanner (TRIOS; 3Shape A/S). An anatomic-contour crown was designed and manufactured by subtractive milling of a partially sintered zirconia blank (3D Multilayer; Aidite Ltd) and sintered at 1450 °C for 2 hours. A base with 4 hemispheres (ø=6 mm and ø=4 mm) cemented on it was fabricated to fix the zirconia abutment (Fig. 1). The 4 hemispheres were used as geometrically recognizable references to facilitate the alignment.[19]

The digitalization of the specimens was conducted by using a dental laboratory scanner (D2000; 3Shape A/S) with an accuracy of 5 μm (ISO 12836). Three scans were obtained (Fig. 1). The intaglio and axial surfaces of the zirconia crown and the abutment fixed in the base were digitized (data crown and data abutment). Then, the intaglio surface of the crown was filled with light-body silicone impression material (Perfit Type 3; Huge Corp) and seated onto the zirconia abutment. A vertical load of 20 N was applied for 5 minutes until the silicone material had polymerized. Excess silicone material was removed with a scalpel, and the crown seated on the abutment was scanned (data seated). The crown was seated and digitized 10 times (n=10).

The scan data sets were aligned and analyzed (Fig. 2) by using a reverse engineering software (Geomagic Studio 2013; Raindrop Inc). Data seated was preliminarily aligned to data abutment by manually defining 4 pairs of corresponding points (the vertex of hemispheres) on the 2 data sets and then aligned. Based on this preliminary alignment, the 4 hemispheres on the base were selected in both data sets, and "Best Fit Alignment" was performed by aligning 7500 data points. "Best Fit Alignment" is based on an iterative closest point algorithm, and it aligns models by minimizing the mesh distance error between each corresponding data point.[20] The root mean square (RMS) of the area chosen for alignment was calculated at 6.5 ±1.1 μm to confirm the suitability of the alignment strategy.

Data crown was then aligned to data seated by using the same alignment strategy. The axial area of the crown, the common area for data crown and data seated, was chosen for "Best Fit Alignment" and achieved an RMS of 9.8 ±1.2 μm, indirectly aligning data crown to data abutment. The relative position of the intaglio surface to the abutment was duplicated in scan data sets. Other areas except for the intaglio surface and the abutment surface were removed.

After inverting the surface normal of the intaglio surface, the cement gap was separated into 3 areas (occlusal, axial, and marginal) for measurement (Fig. 3). For each area, the mean distance between the 2 surfaces, corresponding to the cement-gap thickness, was analyzed by "3D Compare".

The cross-sections were measured in the aligned scan data sets and in the physical silicone replicas to determine whether the relative position of the intaglio surface to the abutment was accurately duplicated in the triple-scan method. After each digitalization of the seated crown, the crown was removed from the abutment leaving a layer of silicone replica on the abutment. A heavy-body silicone impression material (Perfit Type 1; Huge Corp) was applied over the light-body silicone replica film, and after its polymerization, they were removed together from the zirconia abutment. The 10 silicone replicas were sectioned in half. Eight points on each cross-section were selected, and their thicknesses were measured under a microscope

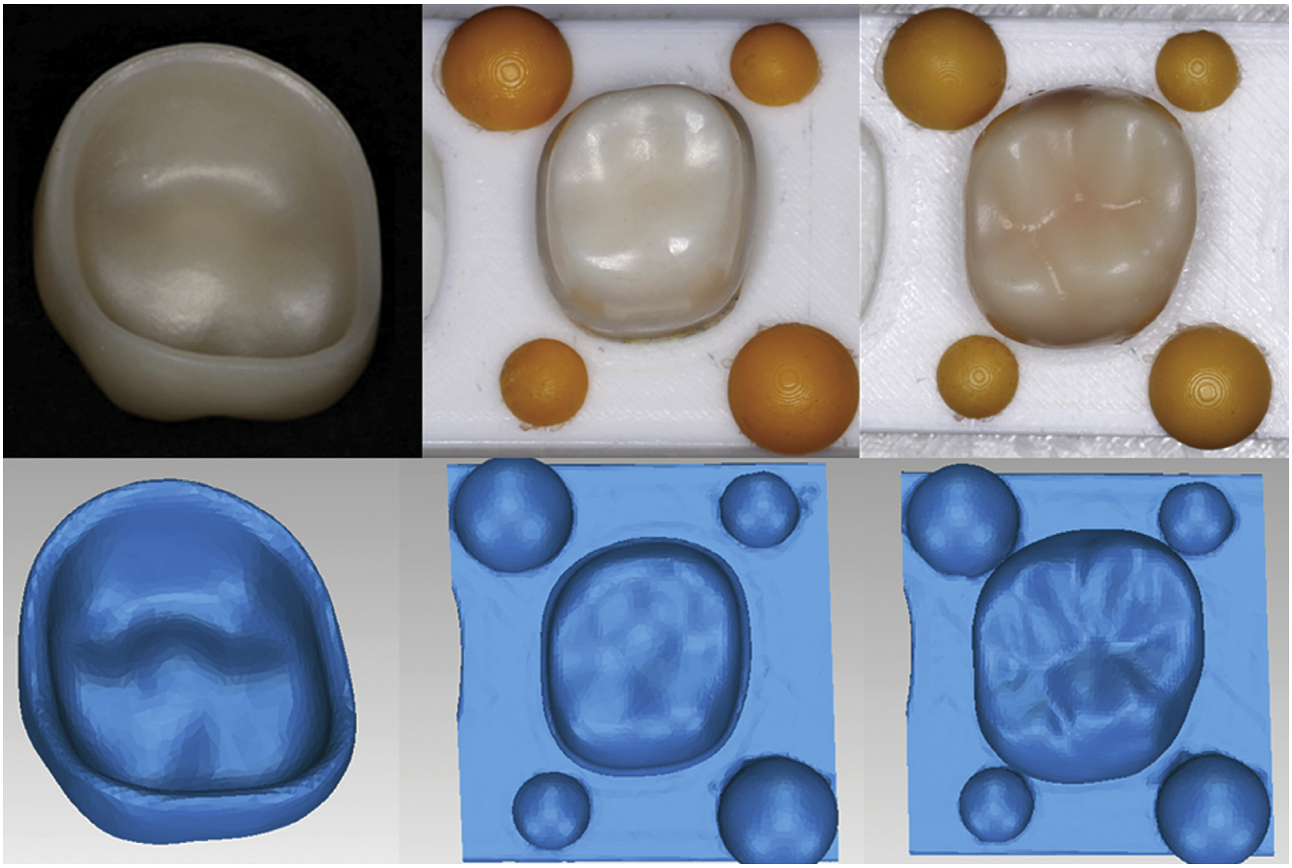

Figure 1. Specimens and scan data sets in triple-scan method. Left to right: crown, abutment fixed in base, crown seated on abutment.

(VK-X200; Keyence Corp) at a magnification of ×200. For every location, 3 measurements were made, and the mean value was recorded. The silicone replica was partially de-adhered from the abutment when removing the crown, and only the undamaged area was used for measurement under the microscope. The same cross-sections were made in corresponding aligned scan data sets, and cement-gap thicknesses at corresponding locations were measured (Geomagic Qualify 2013; Raindrop Inc).

The mean ±standard deviation, maximum, minimum, and coefficient of variation were calculated for the mean 3D cement-gap thickness obtained in the triple-scan method (n=10). Cross-section measurements of the cement gap by using the 2 methods were statistically compared by using the paired *t* test (SPSS Statistics v17.0; SPSS Inc) and the Bland-Altman method (GraphPad Prism 7; GraphPad Software Inc) (α=.05). Normality was tested with the Shapiro-Wilk test.

RESULTS

The relative position of the intaglio surface of the crown to the abutment surface is shown in Figure 2. Representative color-coded difference images of the "3D Compare" results are shown in Figure 3. The thickness of the cement gap was not 3-dimensionally uniform. Table 1 shows the mean 3D cement-gap thickness measured by the triple-scan method. The coefficient of variation of the result was low, being 5.6% for the occlusal area, 1.9% for the axial area, and 6.4% for the margin area.

The cross-section of the cement gap obtained by the triple-scan method was of similar morphology to that of the physical silicone replica (Fig. 4). Quantitative analysis of the cement-gap thickness at corresponding locations reported no significant differences between the 2 methods (*P*=.326, Table 2).

The Bland-Altman plots (Fig. 5) show the difference (triple-scan method minus silicone replica) against the average cement gap thickness measured by the 2 methods. A bias of 0.7 μm and 95% limits of agreement from -12.1 to 13.5 μm were determined, with 3.75% (3/80) of the plots beyond the 95% limits of agreement. The results of the 2 methods were considered to have a clinically acceptable agreement.

DISCUSSION

The purpose of this in vitro study was to evaluate the suitability of the triple-scan method with a dental laboratory scanner for the 3D adaptation assessment of

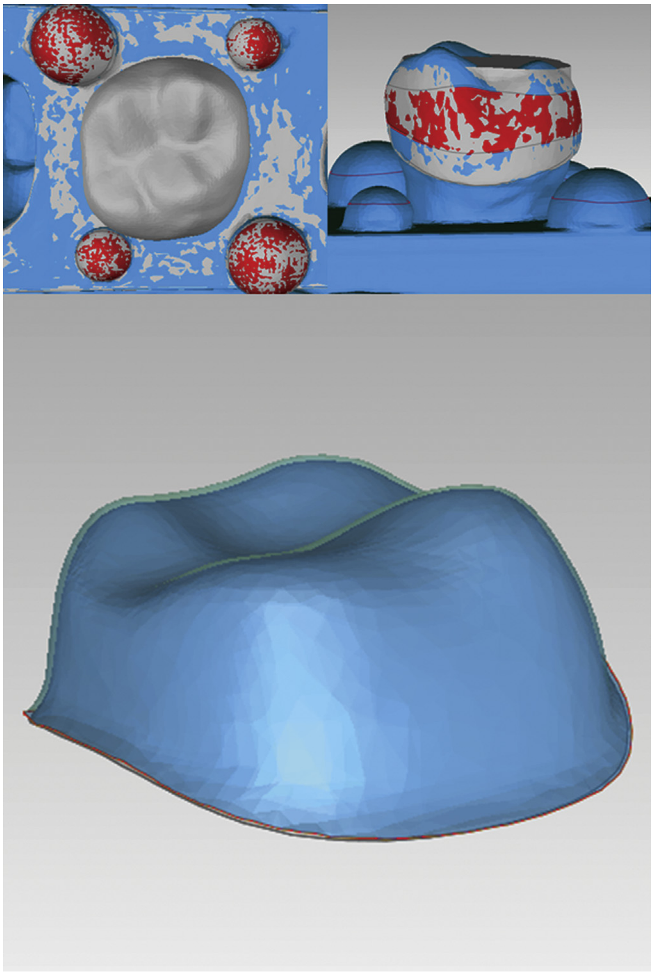

Figure 2. With data seated aligned to data abutment and data crown aligned to data seated, cement-gap between intaglio surface and abutment surface was obtained. Common area chosen for alignment shows interweaving surfaces (*red* and *gray*)

zirconia crowns. A detailed workflow of data acquisition and processing by using a dental laboratory scanner for the triple-scan method was described, and cross-section measurements were carried out in aligned scan data sets and in physical silicone replicas to determine whether the relative position of the intaglio surface of the crown to the abutment was accurately duplicated in the triple-scan method. The null hypothesis was accepted.

This investigation was conducted by using 1 zirconia crown and 1 zirconia abutment to eliminate the error introduced by duplicating specimens. With zirconia ceramics possessing high hardness, elastic modulus, and wear resistance, no deformation or wear of the specimens was considered likely. 3D analysis of the digital cement gap reported that the mean cement-gap thickness had a low data dispersion in repeated measurements, with a coefficient of variation of 5.6% for the occlusal area, 1.9% for the axial area, and 6.4% for the margin area. A standard deviation of several

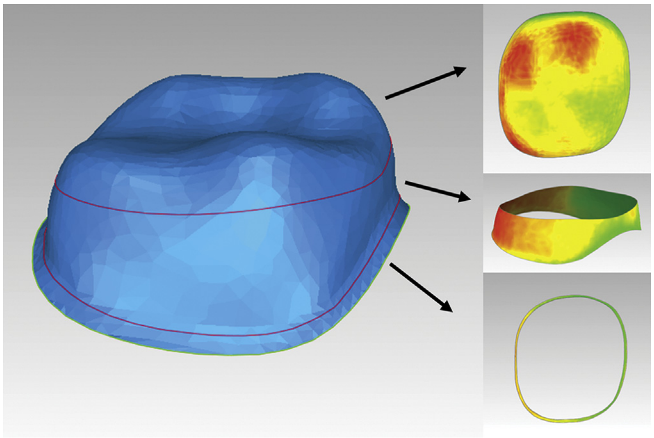

Figure 3. Three areas (occlusal, axial, marginal) defined for analysis by "3D Compare" and representative color-coded difference images showing 3D cement-gap thickness. *Red* indicates large thickness and *green* indicates small thickness.

Table 1. Mean 3D cement-gap thickness measured by triple-scan method (n=10)

Area	Mean ±Standard Deviation (μm)	Maximum (μm)	Minimum (μm)	Coefficient of Variance (%)
Occlusal	102.4 ±5.7	111.2	93.0	5.6
Axial	73.0 ±1.4	75.3	71.0	1.9
Margin	56.0 ±3.6	60.8	49.4	6.4

micrometers for cement-gap thickness assessment is clinically acceptable. The low data dispersion in the present study was achieved by standardizing the seating pressure with a weight and applying a reliable alignment strategy, and the mean cement-gap thickness was calculated based on a large number of points over the cement gap.

In the triple-scan method, the alignment process is critical for the accuracy of the adaptation assessment. Good alignment accurately duplicates the relative position of the intaglio surface to the abutment. The best-fit alignment was conducted based on the common area of featured geometry of the 2 scan data sets in the present study. O'Toole et al[20] concluded that such an alignment strategy is recommended because it results in low alignment errors. According to Peters et al,[21] an RMS value of below 10 μm indicates excellent alignment, whereas an RMS value of above 50 μm denotes a poor fit. Figure 2 shows a good alignment where the common areas of the scan data sets interweave with each other. The RMS values of the areas chosen for alignment were computed at 6.5 ±1.1 μm and 9.8 ±1.2 μm, suggesting good alignment.

Cross-section measurements of the cement gap were made in the aligned scan data sets and in the physical silicone replicas to determine whether the relative position of the intaglio surface to the abutment was accurately duplicated in the triple-scan method.

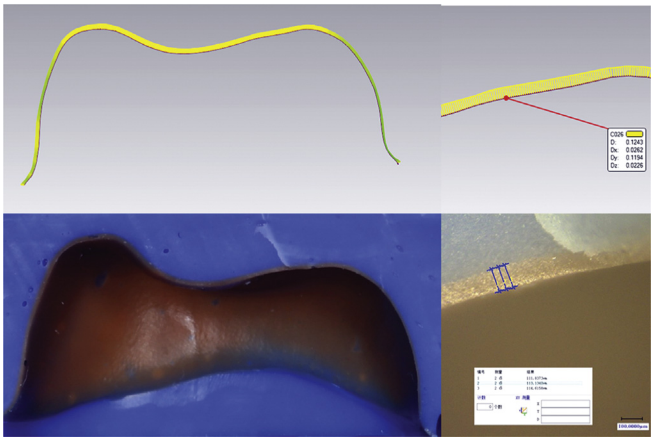

Figure 4. Corresponding cross-section and measurement of cement gap in triple-scan method and in physical silicone replica.

The results reported no significant difference and good agreement. Boitelle et al[14] compared the marginal fit of zirconia copings measured by the triple optical scan method and the silicone replica method, reporting that the triple-scan method produced smaller marginal fit values with less data dispersion. In that study, the marginal fit measured by the silicone method was obtained with 8 measurement points in cross-sections, whereas in the triple-scan method, more points (268 ±82) were measured. Their study was designed to compare the results of the 2 methods, whereas the present study was designed to determine whether the cement gap was accurately duplicated.

The triple-scan method enables a comprehensive 3D adaptation assessment, in which the cement-gap thickness at almost any position can be measured. This is useful because the gap after cementing is not evenly distributed in most restorations.[16] A 2D measurement method with limited measurement points may result in bias with large dispersion. In the present study, a dental laboratory scanner was used, and such a workflow of data acquisition and processing was determined to be suitable, helping to make the triple-scan method more accessible to researchers. Future investigations should explore its suitability for assessing restorations made of other materials such as metal and glass-ceramic.

CONCLUSIONS

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

1. The cement gap was accurately duplicated in scan data sets.
2. The triple-scan method by using a dental laboratory scanner is suitable for assessing the 3D adaptation of zirconia crowns.

Table 2. Paired *t* test of cross-section measurements of cement-gap thickness

Difference	Mean ±Standard Deviation (μm)	95% Confidence Interval (μm)	*t*	*df*	*P*
Triple scan-silicone replica	0.7 ±6.5	(-0.7, 2.2)	0.989	79	.326

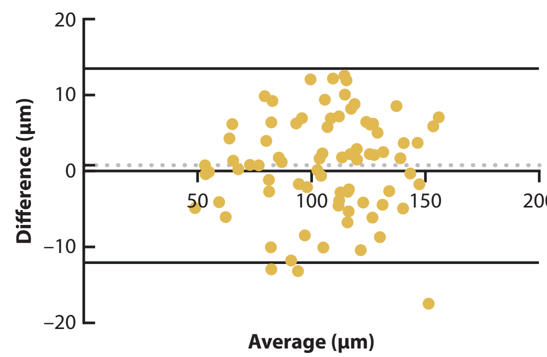

Figure 5. Bland-Altman plots of difference (triple scan minus silicone replica) against average of cement-gap thickness measured by triple-scan method and by silicone replica method. 95% limits of agreement shown by solid lines. Bias shown by dashed line.

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