Clinical and Experimental Health Sciences

Evaluation of Accuracy of Intraoral Scanner with Different Inlay Preparation Geometry

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ABSTRACT

Objective: This in vitro study aimed to assess the accuracy of an intraoral scanner in inlay preparations with different geometry.

Methods: The upper second premolar tooth-shaped models were designed and prepared using a 3D printer (Phrozen Mega 8K, Phrozen, Taiwan). Three distinct inlay preparation configurations were utilized, including buccal and palatal wall divergence at 6°, 8°, and 10°. The reference 3D images were acquired through scanning of each model with varying inlay preparation using an extraoral scanner (E1, 3Shape, Denmark). Thirty 3D images (samples) were obtained from each of the three models (n = 10) using an intraoral scanner (Trios 3, 3Shape, Denmark). The samples and reference images were saved in Standard Tessellation Language (STL) and imported into software (Geomagic Control X 2022, 3D Systems Inc., USA). Discrepancies between the reference image and the samples were recorded as root mean square (RMS) and standard deviation (SD). Kruskal Wallis and Mann Whitney U tests, and interquartile range (IQR) were used for statistical analysis with THE significance level p<.05.

Results: The RMS was highest at 6°, both of which were statistically significant from the other degrees (p<.001). Highest SD values were obtained in 10° samples (p<.001). To evaluate the infer precision with IQR, RMS values were smallest at 10° and SD values smallest at 6°.

Conclusion: The divergence angle of the preparation in the inlay cavities can potentially affect the accuracy of the intraoral scanner.

Keywords: accuracy, divergence angle, inlay, intraoral scanner, precision, trueness.

1. INTRODUCTION

In recent years, intraoral scanners (IOS) have become an integral component of contemporary dental practice. Despite their numerous advantages over conventional methods, many studies have investigated their limitations, as well as the factors affecting scanning accuracy. It is critical to assess the accuracy of IOS to enhance the longevity of indirect restorations. Achieving optimal marginal fit and cement spacing is paramount to prevent microleakage at the restoration's edges, as this can facilitate caries formation and compromise the integrity of the margins (1).

A variety of factors have been shown to affect trueness and precision of IOS. Such factors include lighting conditions (2), operator influence (3), scanning pattern (4), scanning distance (5), scanning area size (6), scanner technology and design (7), and the anatomy of the scanned jaw (8) and tooth position (9). In addition to these factors, many tooth-related factors have been shown to affect scanning accuracy as well. Some of these factors comprise the depth (10), angle (11, 12), and configuration of the preparation (13), as well as the amount of loss in the tooth substance (14, 15).

The assessment of the accuracy of IOS has been addressed by the International Organization for Standardization (ISO), which has established a set of terms and methodologies for this purpose. The term "trueness" is defined as the deviation from the ratios of the reference object, while "precision" is defined as the measurement obtained when the process is repeated continuously. Ideally, an IOS should exhibit both high precision, characterized by a more predictable measurement when the process is repeated continuously, and high trueness, characterized by minimal deviation from the reference object proportions (16). Many research has been dedicated to the evaluation of IOS accuracy. These studies were utilized extraoral scanners,

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which utilize a fixed and unique scanning method to obtain a reference three-dimensional model (17, 18). With precision assessments, although there are studies that evaluate different methodologies (19), one of the most common is the definition of the average absolute distances measured between all scanned specimens and the reference model in terms of the interquartile range (20-22).

Although there are studies that examine various preparation designs and cavity depths in teeth from different locations (9, 10, 23-25), there is a notable absence of studies evaluating the divergence angle (11, 12). To the best present knowledge, there are no studies that have evaluated the accuracy of IOSs in relation to the divergence angle in inlay preparations. Therefore, the objective of this in vitro study was to assess the accuracy of an intraoral scanner in inlay preparations with three distinct buccal and palatal wall angles. The null hypothesis posited that "altering the divergence angle in the inlay cavity does not impact the scanner's accuracy".

2. METHODS

2.1. Production of tooth-shaped model

A total of three different inlay preparation configurations were utilized in the present study. The upper second premolar tooth-shaped models were designed using digital software (ZBrush 2023, Maxon, Germany) and prepared using a 3D printer (Phrozen Mega 8K, Phrozen, Taiwan) to obtain standardized preparations and eliminate the potential for arbitrary preparation (26). The preparation of the cavities was designed with rounded internal line angles, an occlusal isthmus width of 2.5 millimeters (mm), and a contact opening of 0.5 mm on the mesial region with the adjacent tooth. All cavity edges in the mesial area were completed with a 90° cavosurface. An intact margin of 2.5 mm was maintained at the distal region of the model, while an intact structure of 3 mm was preserved at the buccal and lingual cusp areas (Figure 1). The cavity depth was 5 mm with a non-proximal box configuration. The configurations of inlay preparation are outlined as such: the production of buccal and palatal wall divergence at 6°, 8°, and 10° in three distinct models (Figure 2).

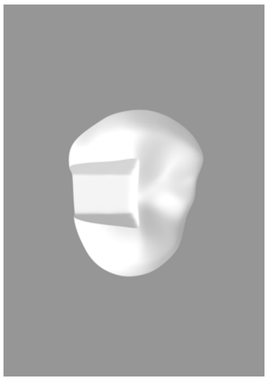

Figure 1. *Three-dimensional inlay preparation design.*

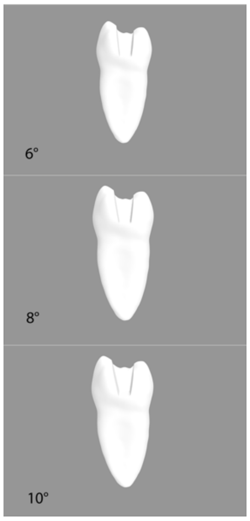

Figure 2. *Inlay preparation design with buccal and palatal wall divergence at 6°, 8°, and 10°.*

2.2. Scanning Procedure

A total of 30 three-dimensional (3D) images were obtained from each of the three models (n = 10) using a Trios 3 (3Shape, Denmark) intraoral scanner. Given the findings of prior studies indicating the Trios 3 scanner's superior accuracy under room light conditions (20), it was imperative that all scans be conducted under identical illumination (room light at approximately 4100 K), in accordance with the scanning direction as outlined by the manufacturer's guidelines. The 3D images (samples) were saved in STL (standard triangle language) format. The intraoral scanners' own illumination was employed during the scanning process, in accordance with the manufacturer's instructions. To acquire the reference sample, each model with different inlay preparation was scanned once using an extraoral scanner (E1, 3Shape, Denmark).

2.3. Evaluation of trueness and precision

Samples were imported into Geomagic Control X 2022 software (3D Systems Inc., USA) to assess the trueness. The reference 3D image and each scanned sample were overlapped, and it was utilized to calculate the "best-fit alignment" tool's analysis of the 3D differences. Discrepancies between the reference image and the samples were recorded as root mean square, or RMS, and standard deviation, or SD. The outer surfaces of the tooth were considered as the reference for alignment, and the RMS values at 150 points selected from the inner surface of restoration area were calculated (Figure 3). Measurement points were randomly selected from the walls and floor of the preparation. The RMS data is calculated by the program based on the following formula:

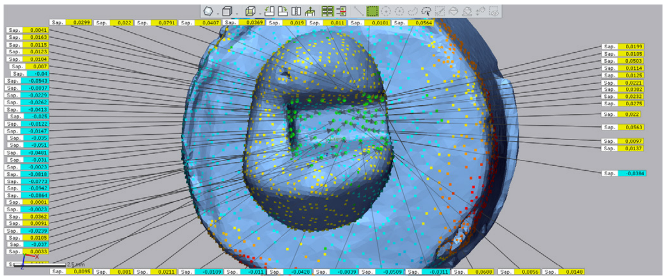

Figure 3. *Calculation of RMS values at 150 points selected from the inner surface of the restoration area.*

$$RMS = \frac{1}{\sqrt{n}} \cdot \sqrt{\sum_{i=1}^{n}(X_{1,i} - X_{2,i})^2}$$

$X_{1,i}$ denotes the measurement point of *i* for the reference models, $X_{2,i}$ denotes the measurement point of *i* for the test models, and *n* denotes the total number of points measured in each analysis. The root mean square (RMS) value is a measure of the absolute distance between the point clouds of the reference and test models. Therefore, an RMS value close to zero indicates a high degree of 3D accuracy. To assess the precision, it was defined in terms of the interquartile range of the average absolute distances measured between all scanned samples and the reference model (20, 22).

2.4. Statistical Analysis

The present study employed IBM SPSS version 29 to facilitate the analysis of the collected data. The root mean square (RMS) and standard deviation (SD) values were presented as median, first to third percentiles, and interquartile range (IQR). The disparities in RMS distributions across different angles were subjected to analysis using the Kruskal-Wallis test, followed by pairwise comparisons with the Mann-Whitney U test, which was adjusted with the Bonferroni correction. A Type I error rate of 5% was designated as statistically significant for all analyses.

3. RESULTS

The distribution of RMS and SD values calculated from samples with different angles is presented in Table 1. For asses the trueness, the RMS was highest at 6°, both of which were statistically significant from the other degrees (p<.001) (Figure 4). Highest SD values were obtained in 10° samples (p<.001). To evaluate the infer precision with IQR, RMS values were smallest at 10° and SD values smallest at 6°.

Table 1. *The distribution of RMS and SD values according to divergence angle.*

Angle	RMS	SD
10°	0.067 (0.065 – 0.069) [a]	0.054 (0.053 – 0.058) [a]
8°	0.046 (0.044 – 0.053) [b]	0.042 (0.039 – 0.043) [b]
6°	0.083 (0.078 – 0.088) [c]	0.041 (0.040 – 0.042) [b]
p*	**<.001**	**<.001**
Angle	**IQR**	**IQR**
10°	0.004	0.005
8°	0.009	0.004
6°	0.010	0.002

**Kruskal Wallis Test, median (1st – 3rd Percentiles), RMS: root mean square, SD: standard deviation, a,b,c There is no statistically significant difference between groups with the same letter, IQR: interquartile range.*

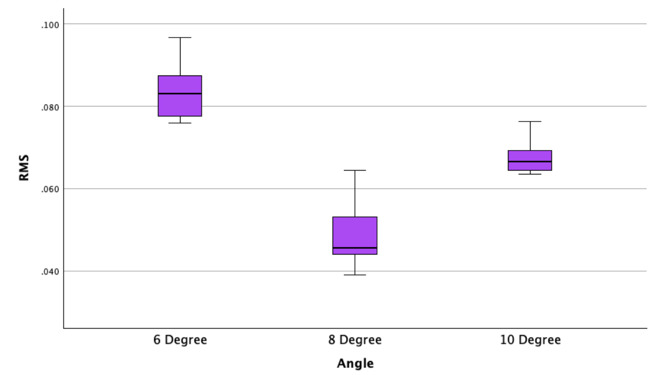

Figure 4. *The distribution of RMS according to angle.*

4. DISCUSSION

The findings of the present in vitro study demonstrated that inlay preparations exhibiting divergent angles affected the accuracy of the intraoral scanner. Consequently, the null hypothesis; "altering the divergence angle in the inlay cavity does not impact the scanner's accuracy" was rejected. Numerous studies have examined the trueness and precision of intraoral scanners and the factors that affect their accuracy (20, 21). In order to produce an ideal indirect restoration, it is essential that the 3D image of the preparation transferred to the design stage is accurate, and that the device possesses high trueness (27). Additionally, scanners are expected to demonstrate high levels of repeatability, which is synonymous with high precision, to ensure the consistency of their performance in accordance with established standards (28). A multitude of factors have been identified as contributors to the accuracy of intraoral scans, including technological aspects, the configuration of the scanner tip, and the resolution of the device (29, 30).

In addition to these factors, the accuracy of the scan can be influenced by clinician-related variables and the configuration of the tooth preparation (12, 15, 23). The objective of this in vitro study was to evaluate the accuracy of an intraoral scanner with confocal microscopy technology in inlay preparations with varying wall angles. Despite the existence of studies that examine various preparation designs or indirect preparations with different amounts of tooth loss and cavity depths (9, 10, 15, 24, 31, 32), there is a lack of studies that evaluate the divergence angle (11, 12). Upon evaluation of the angle-dependent trueness data in this study, it was determined that the preparation at a 6° exhibited the most significant deviation from the reference image with respect to the RMS value. On the other hand, according to SD data, the highest deviation was found in the 10° configuration. This discrepancy can be attributed to the fact that the terms root mean square (RMS) and standard deviation (SD) express differences depending on the calculation process and program.

According to the manufacturer, RMS is a measure of the magnitude of all deviation values, whereas the SD is the standard deviation of all gap distance values. Given that both parameters are evaluated in this study, it can be concluded that 8° for trueness is optimally suitable for both RMS and SD. This is supported by the finding that 6° in RMS and 10° in SD showed the maximum deviation. The results of precision analysis with interquartile range (IQR) data indicated that, consistent with trueness, RMS values exhibited greater deviation at 6° of preparation, while SD values demonstrated the most significant deviation at 10°. Considering the obtained results, it can be concluded that the trueness and precision, the accuracy of the scanner at varying angles, exhibited significant variation. Although Attia et al. utilized a preparation with cavity depths different from those in this study, they found higher trueness in the inlay preparation for the same intraoral scanner with a 12° angle compared to a 6° (32), similar to this study. Likewise, Ashraf et al. found that 6° had a higher deviation from the reference than 12° for RMS values in trueness assessments with Trios 3 in intracoronal inlay preparations (12). In this study, the angles of 6, 8, and 10° were included, in contrast to the 6 and 12° included in the other two studies. However, consistent with previous studies, the highest deviation in root mean square (RMS) values for trueness was found at 6°, while the lowest deviation was found at 8°. One potential explanation for this finding is that, in the present study, a non-proximal box-shaped and 5 mm deep intracoronal preparation design was utilized. Although the preparation angles cannot be adjusted with precision by the clinician under clinical conditions, the effect of the preparation angle on the accuracy of the scanner was observed in this study. It is imperative to note that in recent years, the accuracy of CAD/CAM restorations has become a significant area of concern, as it plays a pivotal role in determining the clinical success of these restorations (33).

Given the acknowledged variability in outcomes associated with the utilization of intraoral scanners (34), due consideration must be given to the design of the cavity and its limitations when evaluating the results. Furthermore, limitations of this study include the use of a single technology intraoral scanner. The Trios 3 intraoral scanner (3Shape, Copenhagen, Denmark) provides ultrafast colored imaging based on confocal microscopy principles with a scanning depth of 17 mm. It captures single pictures, which are stitched together into a three-dimensional network (35). Research has indicated that more recent iterations or advanced technologies tend to demonstrate enhanced accuracy. As demonstrated in previous studies, the accuracy and precision of different intraoral scanners can be influenced by various parameters (12, 23, 36). Furthermore, it is important to acknowledge the inherent limitations of the extraoral scanners utilized in this study, from which the reference file was obtained (37). In further studies, it would be beneficial to examine various preparation configurations by incorporating different intraoral scanners or varying divergence angles.

5. CONCLUSION

Preparations for inlay restorations involving different divergence angles demonstrated that the accuracy of the intraoral scanner varied for both deviation parameters. A similar pattern was observed with precision, which was also influenced by the angles.

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Acquisition of data for the study: BDK, YEO.
Analysis of data for the study: BDK, YEO.
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Drafting the manuscript: BDK, YEO.
Revising it critically for important intellectual content: ZOK, PYA.
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