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Effect of abutment tooth geometry on the accuracy of 2 intraoral scanners: In-vitro study

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***Abstract*---**Aim: The aim of this in-vitro study was to evaluate the effect of abutment tooth geometry on the accuracy of two intraoral scanners. Methodology: The study was conducted using maxillary typodont. Six full coverage crown preparations were performed on central incisors, 1st premolars and 1st molars with known axial wall taper (6^o and 12^o) using dental parallelometer. Highly accurate table-top scanner (Identica T500) was used to obtain reference scan to the typodont. Two intraoral scanners (3shape Trios 3 and Medit i500) scanned the typodont 13 times to obtain total samples of prepared teeth (n=39) for each group. All scans were exported in standard tessellation language (STL) format. Measurements of trueness and precision for respective tooth preparation were evaluated using reverse engineering software for superimposition and deviation analysis. Comparison between groups was performed by using One-Way ANOVA test followed by Tukey`s Post Hoc test and Independent t- test. Results: Statistical analysis showed no significant difference in trueness between the two intraoral scanners. Trueness values were 39.9 µm and 41 µm for Trios 3 and Medit i500. Trios 3 was significantly more precise (23.6 µm) compared to Medit i500 (34.7 µm). Difference in axial wall taper showed no significant difference in accuracy of both intraoral scanners. Conclusions: Trios 3 scanner have better precision than Medit i500. Increasing axial wall taper had

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slight effect on the accuracy of scans obtained by two intraoral scanners.

***Keywords*---**intraoral scanner, digital impression, accuracy, trueness, precision, 3D superimposition.

Introduction

Making an impression of oral cavity is a crucial step of presenting restorative and rehabilitative dentistry. In order to reach success in prosthetic dental treatment, precise impression of the dental arch is fundamental to transfer data to lab technician and fabricate the restoration. The evolution of digital dentistry has been, without a doubt, a dramatic change to the way we perform dentistry nowadays. For example, impression making has moved from conventional impression taking with an elastomeric material to optical scanning with intra-oral scanners. As moving from conventional to digital, a lot of steps and errors could be avoided. Dimensional changes in the impression material after setting, method of impression disinfection, pouring the impression with gypsum material and dimensional changes of gypsum material can all contribute to inaccuracies and errors in the master cast. [1]

The accuracy of dental restorations that are obtained by digital impressions is determined by the accuracy of the whole fabrication chain. The first step of this fabrication chain is represented by the digital impression. This stage will decide the overall system's accuracy, providing that other aspects such as post-scanning software processing, fabrication techniques, and post-fabrication procedures are held constant. Taking an intra-oral scan in comparison to conventional impression saves time. Patient’s data can be sent to the lab via internet, so this also saves time and there is no risk of model breakage during transfer or delayed impression pouring. Moreover, intra-oral scanning is a very helpful tool in evaluating tooth preparation, making sure you got enough occlusal clearance and detection of undercuts. [2]

Accuracy of intraoral scanners is described by two measurement methods: trueness and precision according to ISO 5725. Trueness is the ability of a measurement or measuring device to match the actual value of the quantity being measured, whereas precision is the ability of a measurement or measuring device to consistently repeat a particular measurement. [3] One of the most commonly used methods to evaluate accuracy of optical impressions in the dental literature is accomplished in-vitro on a study dental model digitized with a reference scanner to create a reference 3D model. Digital impressions are made for the dental model. Deviations of 3D models from the reference are calculated after superimposing each model with the reference using special software that is specialized in measuring deviations. [4]

Several factors were found to affect the accuracy of intraoral scanners. Intraoral scanner system, span length, scanning strategy and scanning substrate are among these factors. [5][6][7] Preparation geometry and tooth category affects accuracy of intraoral scanner as well. [8][9] For full-coverage extra-coronal preparations, axial wall taper plays an important role in the success of the definitive restoration in terms of retention, resistance and fitting. Dentist might try to reduce axial wall taper, intentionally or not, in order to avoid over-tapering of the preparation and to obtain better retention and resistance forms. However, this could have negative effect on the accuracy of datasets obtained by direct digital scanning. [10] Therefore, the aim of this in-vitro study was to evaluate the effect of abutment tooth geometry on the accuracy of two intraoral scanners. The null hypothesis was that there would be no difference in the accuracy of scans obtained by different intraoral scanners or different total occlusal convergence of preparations.

Materials and Methods

Six extra-coronal preparations were performed on typodont teeth in a split arch design. Full-coverage crown preparations were done with different occlusal convergence angles. Central incisor, first premolar and first molar on the right side of the typodont were prepared to have 6^{o} convergence angle, while same teeth on the left side were prepared to have 12^{o} convergence angle. A maxillary typodont (Nissin dental model, D18FE-500A-QF, Nissin dental products INC., Tokyo, Japan) with full set of teeth was used to perform preparations and produce the study model.

Reference scan is needed to evaluate trueness of the tested intra-oral scanners. A table-top scanner (Identical T500, Medit, Korea) was used to obtain the reference scan of the typodont. Test scans were divided into two groups according to intraoral scanner type. Group M; Medit i500 (Medit, Seoul, Korea) and Group T; Trios 3 (3 shape, Copenhagen, Denmark). Scanning with intraoral scanners was divided into 3 segments: right posterior, anterior and left posterior to obtain partial arch scans. Scanning each segment was performed 13 times (n=39 for each group) in controlled temperature (23 ± 2 ^{o}C) by one operator. Scanning powder was not used during intraoral scanning since both scanners can work without application of powder.

In order to standardize the preparations and avoid human errors, teeth were prepared using dental surveyor (AF 30 Nouvag AG, Switzerland) with straight hand piece and diamond stones of known taper. Round-end diamond stones (No. z856 öko DENT, Germany) and (No. SD18 öko DENT, Germany) were used to produce preparations with 6^{o} (Sub-order 6) and 12^{o} (Sub-order 12) total occlusal convergence respectively. (Figure 1)

Figure (1): Diamond stone (No. SD18 oko dent, Germany) used to prepare teeth with 12° occlusal convergence

All teeth were prepared to have 1 mm deep chamfer finish line for all-ceramic crown. Preparation length was determined according to tooth type. Occlusal and incisal reduction of teeth was done to obtain central incisors with 6 mm height (Subgroup C), first premolars with 5 mm height (Subgroup P) and first molars with 4 mm height (Subgroup M). (Figure 2)

Figure (2): Completed preparations on typodont

Scanning strategy was the same for both intra-oral scanners. Scanner was moved slowly over occlusal surface and rolled over buccal surface with 45° angle. Then the palatal surface was scanned with 45° angles for each quadrant. All scans were done at the same speed within about 40 seconds. Stereolithography (STL) files were exported for 3D analysis. A reverse engineering software (Medit Compare version 1.0, Medit, Korea) was used to superimpose STL files obtained from each intraoral scanner to the reference scan obtained from table-top scanner. Aligning datasets was done using smart teeth selection tool to select all teeth of both arches leaving out the soft tissue data. Virtual model trimming was carried out to isolate the prepared tooth individually for trueness measurement.

Deviation between the aligned target and reference data was displayed through a color map. The color map appears with maximum deviation range of 0.8 mm and minimum deviation of – 0.8 mm. Acceptable tolerance was customized to 0.01 mm. Green color indicates matching surfaces (± 0.01 mm). (Figure 3)

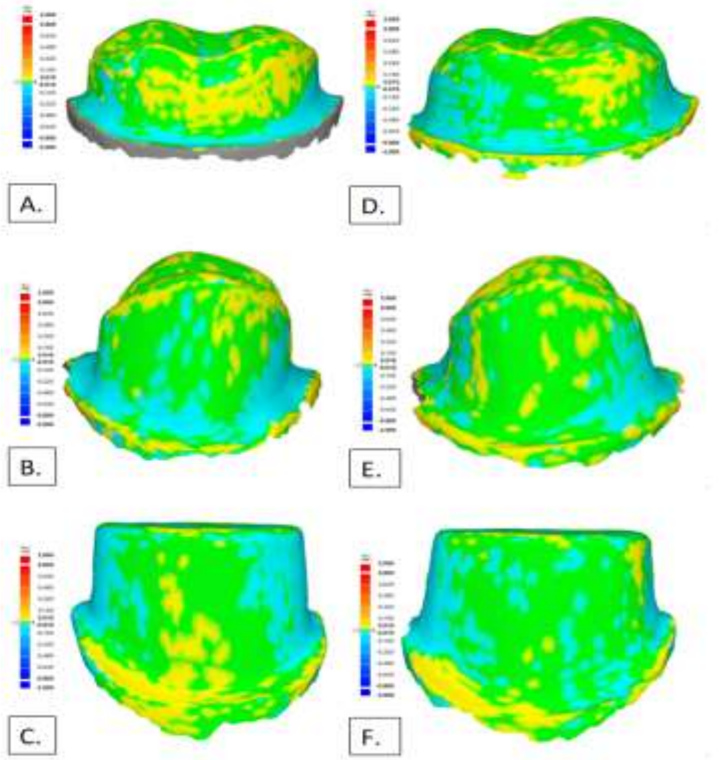

Figure (3): Color map showing deviations of prepared teeth. A, B and C Teeth prepared with 6o occlusal convergence. D, E and F teeth prepared with 12o occlusal convergence

For statistical and quantitative analysis of the deviation between scans, Root Mean Square (RMS) was used. After superimposition of the two datasets, the software calculates the square of the phase difference between a number of points in 3-D space. Then the sum of these squares was divided on the number of points. RMS was calculated as the square root of this value.

Steps to obtain precision measurements was the same except that the comparison was done within the same group. In such a way each scan was considered a reference model and the rest of the scans were superimposed on it.
Data analysis was performed using (SPSS, release 25.0, IBM, Chicago, IL, USA) statistical software. All data were explored for normality by using Shapiro Wilk Normality test and presented as means and standard deviation (SD) values.

Comparison between 2 groups was performed by using Independent t- test. While comparison between more than 3 different groups (quantitative data) was performed by using One-Way ANOVA test followed by Tukey`s Post Hoc test for multiple comparisons.

Results

Concerning effect of intra-oral scanner on trueness and precision regardless abutment tooth geometry, statistical analysis revealed that there was no significant difference in trueness between the two intraoral scanners ($p > 0.05$). However, trios 3 (23.67 ± 7.51) was significantly more precise than Medit i-500 (34.76 ± 12.13) ($p=0.006$, table 1).

Table 1: Mean±SD of overall trueness and precision of group M and group T (µm)

	Trueness (µm) (N= 78)	Precision (µm) (N= 78)
Group M (Medit i500)	41.08 ± 17.32	34.76 ± 12.13
Group T (Trios 3)	39.93 ± 11.82	23.67 ± 7.51
P value	0.628	0.006*

*Indicates significant value

In regard to effect of tooth type on accuracy of intraoral scanners, statistical analysis among subgroups (Central incisors, first premolars and first molars) revealed insignificant difference in trueness among subgroups in sub-order 6 ($p > 0.05$). However, in sub-order 12 subgroup P (first premolar) (33.73 ± 10.84) was significantly more accurate than subgroup C (central incisor) (42.42 ± 12.73). Statistical analysis among subgroups also revealed no significant difference in precision among subgroups.

As to the effect of degree of convergence angle on trueness & precision of the same scanner. Statistical analysis between sub-order 6 (6° occlusal convergence) & sub-order 12 (12° occlusal convergence) in both groups was performed using Independent t-test which revealed insignificant difference in both trueness and precision. ($p > 0.05$, table 2)

Table 2: Comparison of trueness and precision between suborder 6 & suborder 12 in all subgroups regarding Medit i-500 and trios 3 intraoral scanners. (µm)

			Trueness (µm)		Precision (µm)	
			Mean ± SD	P value	Mean ± SD	P value
Group M	Sub-group C	Sub-order 6	46.38 ± 21.08	0.42	35.46 ± 11.72	0.95
		Sub-order 12	40.53 ± 14.87		35.23 ± 8.87	
	Sub-group P	Sub-order 6	42.07 ± 14.44	0.49	36.23 ± 14.73	0.36
		Sub-order 12	38.38 ± 12.75		31.46 ± 11.63	
	Sub-group	Sub-order 6	44.38 ±	0.23	36.15 ± 14.62	0.69

	M		24.68			
		Sub-order 12	34.76 ± 13.57		34.07 ± 12.05	
Group T	Sub-group C	Sub-order 6	44.76 ± 10.04	0.46	25.46 ± 4.61	0.74
		Sub-order 12	44.31 ± 10.43		26.15 ± 6.03	
	Sub-group P	Sub-order 6	32.46 ± 5.78	0.15	21.15 ± 6.81	0.28
		Sub-order 12	29.07 ± 5.95		24.0 ± 6.44	
	Sub-group M	Sub-order 6	48.23 ± 13.87	0.13	24.23 ± 12.39	0.41
		Sub-order 12	40.76 ± 10.79		21.07 ± 6.17	

Discussion

As a result of the release of different intraoral scanner systems in the market, clinicians should be aware of the difference between these systems in technology, scanning workflow and accuracy in order to select the best system that meets their requirements. This study aimed to assess the accuracy (trueness and precision) of two intraoral scanners with regard to different tooth preparation convergence angles. Evaluation of intraoral scanners accuracy has been done using different methods[4]. Superimposition was the method used in this study to evaluate the trueness and precision of intraoral scanners. This method was chosen because it uses multiple points to evaluate the deviation between tested scans in the area of interest[11] .Root Meat Square equation was used for numerical analysis of the deviation[12].

Dental surveyor in conjunction with abrasive stones with known taper were used to perform standardized preparations. Typodont (Nissin Dental Product, Kyoto, Japan) was chosen to complete teeth preparations that have refractive index close to natural teeth[13]. This study used table-top scanner (Identica Blue T500) as reference scanner due to its high accuracy (<7 µm)[14]. In attempt to preserve standard scanning circumstances, scanning time and scanning strategy were kept the same for both intraoral scanners used in this study. Scanning strategy divided the arch into three segments to avoid discrepancies that may appear due to full arch scan due to stitching errors [11, 15].

The first null hypothesis was partially accepted since there was no statistically significant difference between the two intraoral scanners in the overall trueness regardless the type of tooth or total occlusal convergence angle (p value >0.05). However, Trios 3 scanner was significantly more precise (23.6 µm) compared to Medit i500 scanner which showed precision of (34.7 µm). This could be attributed to difference in acquisition methods between intraoral scanners systems. These results were in agreement with Michelinakis et al. [5] , who reported no significant difference in trueness between Trios 3 and Medit i500 intraoral scanners in full arch scans preformed on stone models. However, precision results presented that Trios 3 was significantly more precise than Medit i500. Ashraf et al.[8] also found that Trios 3 and Medit i500 scanners showed no statistically significant difference in trueness as well.

However, the results of this study contradict those of Ender et al.[16] who reported that Trios 3 had trueness of 27.5 ± 1.8 μm which was significantly more accurate compared to Medit i500 which showed trueness of 46.8 ± 2.6 where partial arch scans were performed. Difference in results from this study might be due to the fact that the teeth on their test cast were made of feldspathic ceramic material, which has a higher translucency and thus a different refractive index from teeth made of acrylic in the current study.

Furthermore, Kang et al. [11] and Jin et al. [12] disagreed with the present study where Trios 3 scanner was significantly more accurate than Medit i500. In line with this study, Lee et al.[6] reported mean trueness value of Medit i500 for full-arch scan to be 52.3 μm. For partial-arch segments, clinically acceptable results were found for all IOS devices in this investigation, with variances below 50 μm for all test groups [17, 16] Regarding occlusal convergence and how would it influence the trueness of direct scans, teeth prepared with 12^{o} occlusal convergence in general showed slightly smaller RMS values for trueness compared to those prepared with 6^{o} occlusal convergence angle, although the difference was not significant ($p>0.05$) for all subgroups.

The results of this study come in agreement with Ashraf et al.[8], who reported that increasing convergence angles of full coverage preparation would produce more accurate scans. On the other hand, Carbajal Mejía et al.[10] reported that accuracy of intraoral scanners was not affected by abutment tooth geometry when different convergence angles were used for single die full-coverage preparation. Another study by Chan et al.[18], reported that accuracy of direct digital scanning was not affected by axial walls convergence except in the range of zero degrees. On the other hand, Jeon et al.[19] agreed with the present study since he reported that increasing axial wall inclination improves accuracy of intraoral scanners.

In this study, there was no difference in the trueness nor the precision between different teeth types within the same group (same intraoral scanner). This could be attributed to scanning strategy of the current study, where each sextant was scanned separately offering the highest accuracy. Consistent with this study, Su & Sun[20] reported that molar full coverage preparation was insignificantly more accurate than central incisor preparation when scanned with Trios intraoral scanner. A study by Kang et al.[11] reported that posterior region had lower accuracy than anterior region when several intraoral scanners were used to obtain complete arch scans.

On the other side, Rudolph et al.[21] found that incisor preparation showed more deviation in relation to molar preparation. This difference was attributed to the fact that incisor or molar preparations offer different angles (obtuse or sharp) and shadowed parts, which cannot be captured precisely, or steep and parallel opposing tooth surfaces. Therefore, steep and parallel incisors are the most difficult areas to capture for most intraoral scanner devices. There are certain limitations to this research. For example, this study relied on in vitro tests, which do not accurately reflect conditions in the oral cavity (moist environment and limited space). Additionally, the designs of the preparations and the adjacent teeth were standardised. In actual patients, there could be some amount of variation. Moreover, in this investigation only two types of IOS were used. There are numerous IOS on the market, each with its own set of characteristics.

Conclusion

1. Trios 3 provided more precise scanning than Medit i500 in scanning full-coverage preparations.
2. Both Trios 3 and Medit i500 intraoral scanners showed accurate scanning (Trueness) for full-coverage preparations
3. Abutment tooth geometry and axial inclination didn't affect the accuracy of intraoral scanners.

Conflict of interest
The authors have no conflict of interest to disclose.

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