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Effect of Preparation Depth for an Endocrown on the Trueness and Precision of Intraoral Digital Scanners

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Aim: The aim was to evaluate the trueness and precision of four different intraoral scanners for scanning endocrown preparations with two depths (4 mm and 6 mm).
Materials and methods: Tooth preparation for an endocrown was done and scans were divided according to depth of the preparation. The tooth scans were divided into 2 groups, Group A an endocrown with 6 mm depth and a butt joint margin of 2 mm thickness all around, Group B an endocrown with 4 mm depth, then each group was divided into 4 subgroups according to the intraoral scanner used for scanning, Omnicam v. 4.4.4, Omnicam v.4.4.6, Medit i500, 3Shape Trios 3 respectively, Reference scan were obtained from InEoS X5 extraoral scanner, and 10 test scans of each cavity were made with 4 IOSs. The STL files obtained were compared to reference models (trueness) and within each test group (precision) using a 3D analysis software program (Geomagic Control X). Obtained data were analyzed with three-way ANOVA.
Results: Regarding trueness, Three-way ANOVA revealed significant differences between the different types of scanners ($p < 0.001$) (Omnicam 4.4.4: 56.53 ± 6.08 Omnicam 4.6.2: 47.68 ± 12.11 Medit i500: 52.07 ± 8.92 Trios 3: 38.81 ± 8.72). Preparation depth showed significant influence on the trueness ($p < 0.001$) (6 mm depth 55.70 ± 8.22, 4 mm depth 41.84 ± 9.46). For precision three-way ANOVA revealed significant differences between the different types of scanners ($p < 0.001$). Preparation depth also had significant influence on the precision ($p < 0.001$).
Conclusion: Change of depth of preparation greatly affect the trueness and precision of the for Intra-oral scanners.

Keywords: Endocrown, Intraoral Scanners, Accuracy, Depth

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Introduction

With the advancement of digital dentistry over the last years, it became so important to evaluate all the computer aided design/computer aided manufacturing (CAD/CAM) devices. Several scanners were introduced in the market and since then a great number of intra-oral scanners have appeared with different technologies aiming for capturing scans with a high resolution and accuracy.(1) With the increased pace of life, increased awareness, rising esthetic and functional demands and high expectations from both patients and dentists, the development of a faster and more precise prosthetic solutions became of paramount importance. The success rate of prosthesis depends on several factors, an accurate impression is one of the most important factors to ensure a proper prosthesis from a functional and esthetic aspects. (2) Conventional impression was utilized to be the sole solution for capturing intra-oral data and send it to the laboratory where all the traditional steps were performed starting from disinfecting the impression to pouring, casting, investing down to fabrication of the prosthesis.(3–9)

Digital intraoral scanners (IOS) can be classified accroding to the optical principle used for data capturing. The most common principles used are active triangulation, confocal microscopy, optical coherence tomography and active wavefront sampling.(10,11)

The digital process of capturing an image of the preparations eliminated the drawbacks produced by the conventional impression such as the risk of storage and damage, the prolonged overall treatment time, the inconvenience and intolerance regarding the patient and the risk of contamination.(12–14) The development of digital dentistry depends on studying several intraoral scanners (IOS) and their accuracy. The accuracy of impression is described as trueness and precision. Both pillars have their own definition, where Trueness is the 'closeness of agreement between the expectation of a test result or a measurement result and a true value', while Precision is defined as the 'closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same objects under specified'.(13) Several factors affect both trueness and precision of digital scanners as excessive reflection due to metallic restorations or excessive saliva or with areas poor access, areas with mobile tissues, or edentuolous spaces all of these will affect the quality and the sharpness of captured image. Further, light obstruction will cause shadowing and loss of the entire shadowed area like: steep surfaces, sharp edges, proximal areas and gingival margins. (15)

Over the past few years, the preservation of tooth tissue became important specially as dental materials showed a great development which lead to less aggressive micromechanical approaches following new principles; minimally invasive dentistry which paved the road to partial coverage restorations such as Inlays, onlays, endocrowns, and veneers as variants to the conventional preparations and the involved new materials like glass ceramics, hybrid materials, and composite materials.(16–20) Endocrown restoration is described as a monolithic one piece ceramic restoration, which restores a preparation consisting of a circumferential butt margin and a central retention cavity inside the pulp chamber. This approach utilizes the surface of the pulp chamber to ensure stability and retention of a restoration through adhesive bonding.(21) It also follows the concept of decay oriented design leading to a minimally invasive preparation. It is treated like other restorations, where the preparation follows definite guidelines, modifications of these guidelines can be followed to obtain optimum esthetics, or because of biomechanical aspects. These modifications include the application of immediate dentin sealing, extension of finish line on other surfaces, or decrease the axial height of cusps, or even the inclusion of proximal cavity box to the preparation design. (22)

Endocrowns are especially indicated in cases of Molars with short, obliterated, dilacerated, or Fragile roots. Also, they may be used in situations of excessive loss of coronal dental tissue and limited interocclusal space, in which it is not possible to attain adequate thickness of the ceramic covering on the metal or ceramic substructure. (17,23,24)

The object of the study was to evaluate and compare the trueness and precision of four different intraoral scanners (Cerec AC Omnicam v.4.4.4, Cerec AC Omnicam v.4.6.1, Medit i500 and Trios 3 by 3Shape), for scanning endocrown preparations with two depths (4 mm and 6 mm).

The first null hypothesis was that the accuracy of the intraoral scanners is not affected by the depth of the design. The second null hypothesis was that different scanning technologies and software of the intraoral scanners do not affect its accuracy.

Materials and Methods

Teeth scans of endocrown was divided into two groups: Group A for 6 mm depths, and Group B for 4 mm depths. Each group was divided into 4 subgroups: Subgroup I (Omnicam 4.4), Subgroup II (Omnicam 4.6), Subgroup III (Medit i500) and Subgroup IV (Trios).

One sound caries free freshly extracted Maxillary first Molar was selected for the scans. Access to the pulp chamber according to the teeth morphology was done using a round carbide high speed bur. Protaper system (Dentsply; Ballagues, Switzerland) was used to standardize the root canal treatment. F2 rotary files were the final files used to reach the master file, while F3 rotary file were used as a master file for the palatal canal combined with irrigation using sodium hypochlorite after each file. F3 protaper paper point were used to dry the palatal canal and F2 for buccal canals. Resin based root canal sealant (ADseal, META BIOMED, Chungbuk, Korea) was used with F2 gutta percha for buccal canals and F3 for palatal canal. and then excess gutta percha was removed using a hot red condenser. The specimens was then embedded in auto-polymerizing acrylic for easy handling (Rebaron GC Corporation, Tokyo, Japan) .

The specimens received butt margin preparation and all undercuts were removed using a diamond abrasive stone with flat end, to obtain a smooth preparation, finishing was done using diamond abrasive stone with yellow code, the floor was made sure to be at 6 mm depth from the butt joint margin using university of north carolina no. 15 probe. The tooth was scanned using the reference scanner (InEos X5, Dentsply Sirona, Bensheim, Germany), then using the intraoral scanners, STL files were exported for each scanner.

For Group B, the specimen received flowable resin composite restorations over the pulp chamber orifices to achieve a pulp chamber floor parallel to the butt joint margin at depth of 4 mm, this was done using a one-step adhesive (All-Bond Universal, Bisco) and a flowable resin composite (3M Filtek Supreme Flowable Restorative), applications were done following the manufacturer instructions, finally a polywave LED based visible light cure (VLC) unit (Bluephase G2, Ivoclar Vivadent) was used for light polymerization. Then the same scanning steps were performed to obtain Group B STL files. (Figure 1)

The scanning procedure was done according to the manufacturer's instructions, overlapping of surfaces was always ensured. Each scanner was calibrated before every scan.

First reference STL files was required to evaluate the scanners trueness, these files were obtained using extraoral desktop scanner (InEos X5, Dentsply Sirona, Bensheim, Germany). Then specimens were also scanned by the intraoral scanners 10 times for each scanner, a total of 80 STL files were collected and then trimmed. (10 scans for each subgroup).

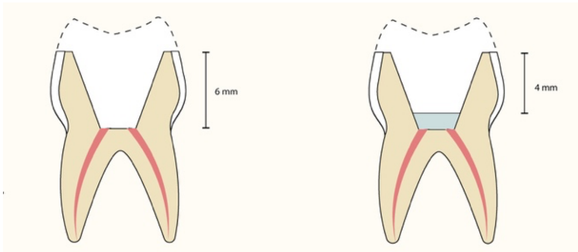

Figure (1): Diagram showing the two preparation depths.

To measure the trueness of the intraoral scanners, a certain reverse engineering software was used (Geomagic Control X 2018, 3D systems, NC). We started by importing the reference STL file followed by trimming everything that would affect the results, leaving the tooth and part of the base. Each test scan file was added and trimmed as well, initial fit was done to superimpose onto the reference model followed by best fit alignment. After alignment, the 3D compare function shows the deviation calculation, a color coded map is generated which shows the deviation pattern where red indicates positive deviation and blue indicated negative deviation of the test scan. Finally, a report was generated showing Root mean square (RMS) values, they were collected and tabulated.

To measure the Precision, STL files from each scanner was used as both reference and test scan, where one scan was used as reference, the rest was used as test scans and superimposed on each other.

STL files of each group were superimposed 1 by 1 on the imported reference STL file of our model to calculate the Trueness and the data of the root mean square (RMS) of each superimposition was collected (25–27) to evaluate quantitative accuracy, since it shows a high estimate of the average error, and an average value was calculated, where lower RMS values are better.

STL files of each subgroup were superimposed on each other to calculate the Precision. Each scan was used as a reference model for the remaining scans of the subgroup.(28,29).

Statistical Analysis:

Checking of the data collected for normal distribution was done using Kolomgrov–Smirnov and Shapiro–Wilk tests and analyzed using one-way, two-way and three-way analysis of variance (ANOVA), followed by Tukey's post hoc test, statistical analysis was performed with IBM® SPSS® Statistics Version 26 for Windows. (SPSS v20, Chicago, IL) at a significance level of $p \leq 0.05$.

Results

RMS values were considered as the main values of comparison, which shows the square root of the mean square of deviation values, where a value of 0 means a perfect scan, which can't be true, a lower RMS values shows a better fit or alignment, while a higher one shows less fit or alignment. All RMS values were collected for statistical analysis, the results of the different tests showed the following: (Table 1)

Table (1): Mean ± standard deviation (SD) of RMS (trueness and precision) for different scanners and depths

Accuracy	Preparation depth	RMS (mean±SD)				p-value
		Omnicam 4.4	Omnicam 4.6	Medit I500	Trios	
Trueness	4 mm	57.36±3.13^{A}	39.10±0.95^{C}	51.25±2.94^{B}	35.75±4.34^{C}	<0.001*
	6 mm	57.67±3.48^{B}	64.65±2.48^{A}	60.99±3.43^{B}	51.63±1.74^{C}	<0.001*
	p-value	0.811ns	<0.001*	<0.001*	<0.001*	
Precision	4 mm	40.93±1.41^{C}	47.09±6.17^{B}	52.84±8.57^{A}	32.20±1.45^{D}	<0.001*
	6 mm	56.42±0.47^{B}	40.77±2.96^{C}	61.75±5.59^{A}	45.31±4.39^{C}	<0.001*
	p-value	<0.001*	<0.001*	<0.001*	<0.001*	

Means with different superscript letters are statistically significantly different within the same horizontal row *; significant ($p \leq 0.05$) ns; non-significant ($p>0.05$), lower values are better

Trueness Results:
Significant difference in trueness of the four intra-oral scanners due to the change of depth in the preparations, samples with 6 mm depth (55.70±8.22) had significantly higher value than samples with 4 mm depth (41.84±9.46) ($p<0.001$). (Figure 2)

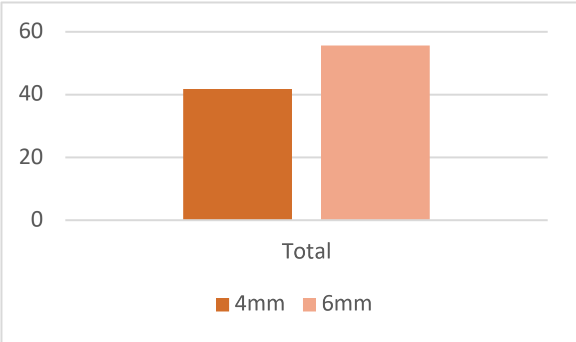

Figure (2): Bar chart showing average RMS (trueness) for different preparation depths

The subgroups showed significant differences, which corresponds to different technologies of scanners ($p<0.001$). where the highest RMS was found with Dentsply Sirona Cerec AC Omnicam 4.4.4 (56.53±6.08), followed by Medit I500 (52.07±8.92), then Omnicam 4.6.2 (47.68±12.11), while the lowest and the best value was found with Trios 3Shape (38.81±8.72). (Figure 3)

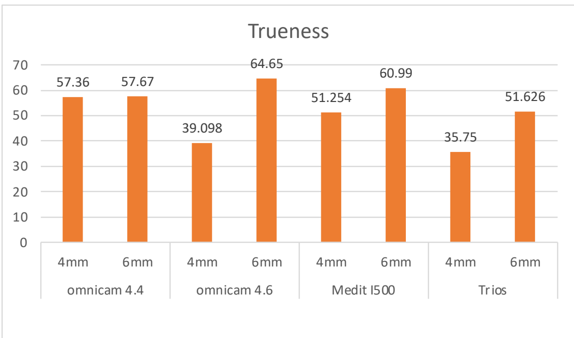

Figure (3): Bar chart showing average RMS (trueness) for different scanners, and preparation depths

Precision Results:
It was found that there were significant differences in precision due to the change of depth of preparations ($p<0.001$). Where Omnicam 4.4 had the highest RMS value (50.79±10.06), followed by Medit I500 (48.94±10.39), then Omnicam 4.6 (42.95±5.04), meanwhile the lowest and best value was found in Trios 3Shape (37.37±7.05).(Figure 4)
Significant difference in Precision of the four intra-oral scanners due to the change of the preparation depths, samples with 6 mm depth (49.17±9.87) had significantly higher value than samples with 4 mm depth (40.85±8.02) ($p<0.001$).(Figure 5)

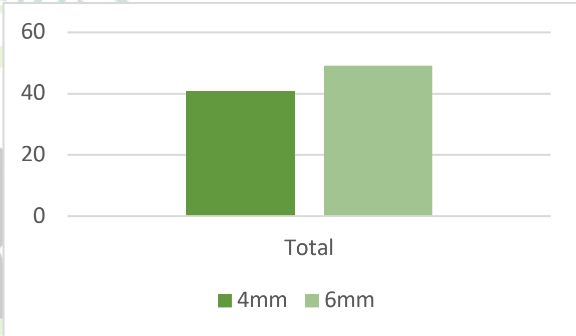

Figure (4): Bar chart showing average RMS (precision) for different preparation depths (lower values are better)

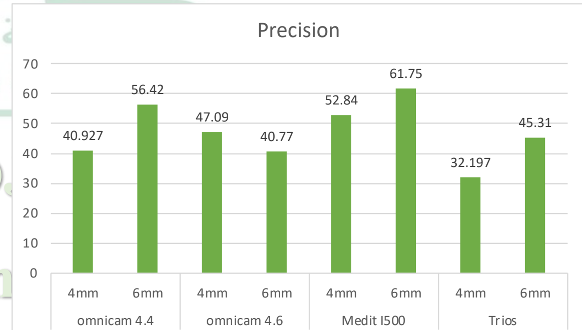

Figure (5): Bar chart showing average RMS (precision) for different scanners, and depths (lower values are better)

Discussion

The advancement of digital technology has pushed the advancement of manufacturing from casting all metallic restorations to layering of porcelain fused to metal restorations and finally milling and pressing of monolithic ceramic restorations, it is now being applied in the field of dentistry even in diagnosis and treatment planning, and it has become a trend in fixed prosthodontics(30).

To enhance the impression procedure, different intra-oral scanning systems have been launched to the dental market for direct digitalization. Hence it has become of prime importance to accurately evaluate these devices measuring deeper depths of preparations (31)

CAD/CAM was first introduced in the field of dentistry for single-unit restorations. Nowadays, it is possible to produce complex multi-unit restorations by the help of advancements in the technology. Computer aided Imaging (CAI) allow to directly acquire the data of the prepared abutment and reduce time and errors involved. So, to obtain a precise dental restoration, it is important to have an accurate impression.

The aim of our study was to evaluate the accuracy of four intraoral scanners by the means of trueness and precision in 2 preparation depths of an Endocrown. Increasing the depth of the preparation affects the retention, the bulk of the restoration and hence the overall durability of the restoration. Endocrown is considered to be a more conservative alternative to the traditional post, core and full coverage crown that requires a greater amount of tooth preparation, this coupled with the recent advances in bonding of all ceramic restorations were the main reason for the selection of an Endocrown to be the focus of our study. (16,32)

Every CAD CAM procedure should follow multiple steps, and each step has a potential to be the source of an error. Therefore, each procedure in the workflow is important and can cause an effect to the overall performance that's why trueness and precision are among the essential factors and it is important to highlight its effects. As trueness parameters cannot be evaluated in-vivo easily because of missing reference structures (31), so we chose our study to be done in-vitro.

In this in-vitro study, we used human natural teeth to ensure more simulation to clinical conditions with respect to tooth structure and morphology which is more accurate and clinically reliable than artificial teeth, this will prevent the production of artifacts that would affect the accuracy measurement of the intra-oral scanner. (33)

The InEos X5 was assigned to be the reference scanner because it has accuracy of less than 15 µm which is considered as a minimum deviation according to literature and almost equivalent to the accuracy of Poly Vinyl Siloxane (PVS) impression. (34,35)

There are several factors that can affect the reproducibility of an IOS, these factors include scanning technology, data processing algorithm, and image acquisition method (36). That's why in our study we focused on standardizing the factors as much as we can to get accurate results. Regarding the scanning time, time was fixed to 30 seconds to exclude the time factor on the trueness and precision of the intra-oral scanners, all operating rooms were illuminated with an LED white light using light bulbs of equal intensity (37).

The four intra-oral scanners chosen were due to their high availability in the market and because of the difference in the scanning technology utilized by every scanner, where Trios 3 uses parallel confocal imaging, Omnicam uses Active triangulation, and Medit uses Phase shifting optical triangulation. No powder was needed to scan with the four intra-oral scanners, since some studies(36,38–41) concluded that they had an effect on accuracy.

A single operator familiar with all the scanning procedures was responsible for performing all the scans to minimize the risk of any discrepancies, all scanning strategies were done according to manufacture recommendations regarding the direction of motion of the scanner head during data acquisition to make sure that every scanner is yielding the best possible outcome regarding its accuracy (42,43)

The accuracy was expressed in terms of trueness and precision as it is a common method that was applied in previous studies.(44–47)

The method of superimposing two surfaces after best fit alignment has been used in engineering and in several in vitro studies, which is called 3D compare analysis (31,37)

Regarding the effect of depth and complexity of preparation on the accuracy of the four intra-oral scanners, the first null hypothesis was rejected as statistically significant differences was observed in the accuracy of the four intra-oral scanners due to changing the depth of the preparations.

The technique of digital impression using light depends on reflection, which is easier and accessible in shallow surfaces, unlike deep surfaces which produce surface noise, although the surface noise is eliminated by the software filtering, software processing can cause rounding of sharp edges, and loss of surface details. Therefore, producing inaccurate images.

This was in disagreement with Park et al in 2019 (41). Since they reported that there was no significant effect on the accuracy when the depth of intra-coronal preparation was changed. Also Khaled et. Al in 2021 (39) reported that the accuracy of the 4 IOS scanners used (Trios 3, Omnicam 4.4.4, Omnicam 4.6.1, and Medit I500) were not affected by changing the depth of the preparation of an inlay retained bridge (2 mm and 3 mm depths)and this was because the depth used in our study is much greater than the ones used in those studies inwhich both were done on inlay preparations, therefore that had a significant effect on the depth of field of the IOS used.

However, similar results were reported as Shin et al. in 2017 (40) concluded that marginal and internal deviations increased when depth was altered after investigation of CAD/CAM endocrown preparations with 2 different preparation depth, 2 mm and 4 mm depths using 2 chairside systems (CEREC AC and E4D).

Also Gaintantzopoulou and El-Damanhoury (48) tested endocrowns with different depths (2-mm, 3-mm, 4-mm) that were scanned using (CEREC Bluecam; Dentsply Sirona), they reported that the increase of depth of preparation causes an increase in marginal and internal discrepancy, and our study results were consistent with their results. The decrease in overall trueness (higher values) could be attributed to the increase in the preparation depth.

Furthermore, Gurpinar et al. in 2020 (38) who concluded that a pulpal chamber extension depth with a 2 mm depth showed better trueness than pulpal chamber depth with 5 mm.

Regarding the effect of scanner type on the accuracy of the intra-oral scanners, the second null hypothesis was rejected as our results showed that the accuracy of the four intra-oral scanners had significant differences which might be due to the fact that Trios uses different technology, which is confocal microscopy that is a much superior technology to the Omnicam and Medit I500 triangulation technology.(10,11)

Moreover, software processing of these IOS affect the quality of the images, in which Trios uses optical sectioning by obtaining high resolution optical images with depth selectivity, also a feature of telecentricity in space, which means the ability of shifting the focal plane without any change of magnification ratio(49,50)

These results coincide with with Park et al in 2018 (41), Ender et al in 2019 (51) and Mattia Sacher et al in 2019 (52) as they reported accuracy was different significantly between iTero, Medit I500 and Trios 3, with Trios 3 showing the best accuracy, the same reverse engineering software was used to compare the 3D Models and analyze the data using RMS values.

These results were not in agreement with George Michelinakis et al in 2019 (53), whose results showed that the Medit I500 scanner was of better accuracy than the Trios scanner. This may be attributed to the fact that the cast used during his study was made of gypsum with different refractive index than that of natural teeth.

Improvements in intraoral scanners will remain day after day paving the road for more accurate scans and more applications maintaining the door open for future researches to evaluate their accuracy and precision.

Conclusion

Change of depth of preparation greatly affect the trueness and precision of the for Intra-oral scanners.

It is recommended to choose scanners like Trios 3 and Omnicam 4.6 in case of scanning deep endocrown preparations rather than Omnicam 4.4 and Medit i500

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