VALIDITY AND RELIABILITY OF DIGITAL MODELS GENERATED FROM CBCT SCANNING

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ABSTRACT

INTRODUCTION: Dental study models are essential for implant treatment planning, for fixed and removable prosthesis and for orthodontic diagnosis, treatment planning, and follow up. Digital dental workflow has invaded modern dental treatment and digital modelling has prompted ongoing research. Digital or virtual models could be generated by various techniques.
OBJECTIVE: To evaluate the validity and reliability of three-dimensional (3D) digital or virtual models produced using CBCT scanning of dental impressions or casts. **Methodology**: Two techniques were used to obtain 3D virtual model files including scanning of impressions by CBCT machine besides scanning of the corresponding casts by the same CBCT machine (N=36). Four linear measures (canine to molar, inter-canine, inter-molar and vertical dimensions) were measured in all virtual models and compared with the caliper measurements of the stone model. Additionally, Stereolithography (STL) files from the two techniques were registered with that obtained from a desktop scanner by using a best-fit matching in a three-dimensional modeling program. This program measured the mean differences between the virtual meshes and qualitative assessment was performed through the obtained color maps.
RESULTS: Some linear measures and the 3D deviation analysis revealed statistically significant differences but all were considered clinically accepted.
Virtual models created by CBCT scanning of casts exhibited less differences ranging from (0.17/ -0.02 mm), whereas CBCT scan of impressions revealed mean discrepancies with a range (0.16/ -0.04 mm).
CONCLUSION: CBCT scanning of the impressions and stone casts provided acceptable results but with granular surface of the model. Both methods could be used in clinical setting provided that highly accurate devices are used. ***Keywords*:** CBCT, Cast, Dental impression, Digital model, Validity
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INTRODUCTION

Recent digital integrations have greatly invaded various dental specialties (1). Dental technology has been advanced strongly during the past two decades and the application of software and digital workflow have been suggested to have the most impact. Digital dental workflow involves four major steps: scan, design, production planning and production. In each of the steps, different software packages and digital systems are being used (2). The increasing applications of digital modelling has motivated the researchers to prove the accuracy of this technique (3). In computer guided implantology, multiple devices are needed to create a virtual patient for accurate planning. Among these devices, cone-beam computed tomography (CBCT), facial scanners and either intraoral or desktop scanners are frequently used (1-4). In fixed prosthodontics, the scanning process is essential to produce digital models necessary for the restorations milling process. This process is usually done by an intraoral (5) and desktop scanner or laboratory scanner (6). Moreover, study models are crucial in any orthodontic treatment for proper diagnosis, planning and subsequent follow up.

The most commonly used technique to obtain virtual or digital models is laser scanning of plaster or stone cast poured from an impression (7). On the other hand, another recent method to obtain virtual model is the use of intraoral scanner that directly scan the dental arches (8). However, this relatively new device is not available in all dental offices owing to its cost and relatively long duration needed to scan the whole oral cavity (7,9). Another technique to get a virtual model utilizes cone-beam computed tomography (CBCT), which is data acquisition method that scan the whole volume of any object quickly without being affected by the amount of undercuts in the deep proximal areas (10). Recently, CBCT resolution was being refined from 0.4 to 0.07 mm for better 3D visualization of the maxillofacial area (11). Thereby, digital model production using CBCT scans of patient impressions and casts is an alternative method to intraoral scanner or a desktop scanner without the need for directly irradiating the patient. Moreover, single impression can be used for both virtual and stone models fabrication if needed (12,13).

Of particular interest is the reliability and accuracy of some of these newer techniques and their applications in-vivo in relation to well established methods, such as conventional stone casts as the previous studies were conducted mainly in-vitro.

The null hypothesis of this study was that the accuracy of virtual models obtained from various techniques and that of conventional stone model is comparable.

MATERIAL AND METHODS

The study was approved by the Faculty of Dentistry research ethics committee (protocol number: 0008839) and the enrolled patients have assigned an informed consent prior to commence the research.

The sample size was calculated using 95% confidence level and G power 3.0.10.

Thirty-six patients (pts) were recruited from the outpatient clinic of Periodontology department, Alexandria University.

The inclusion criteria of the recruited pts were as follows: (a) Young patients with age range 25-35 years (b) no sex preferences and (c) full dentate patients with normal occlusion

The exclusion criteria were: (a) patients with any metallic appliances and (b) patients with crowded teeth.

Virtual model preparation from impressions

Bimaxillary impressions were made by using a plastic tray and rubber base silicone material (Zetaplus, Zermack) for each patient. Within the same day, the impressions were scanned using a Cone Beam Computed Tomography machine (Veraviewepocs, J Morita) using the following settings: 90 kV, 10 mA, 80 x 80 x 80 µm voxel size, and 80 x 50 mm field of view (FOV) (Figure 1). The raw data obtained with CBCT were reconstructed into 3D images (segmentation was performed using -350 -1553 voxel value in a new mask) and then converted to the stereolithography format using a 3D imaging program; Mimics software (Materialize Innovation Suite, Leuven, Belgium 22.0) by converting the voxels ultra-structure of DICOM data to a triangulation format. Then, these images were imported in a 3D modeling program (Autodesk Meshmixer 3.5; Autodesk). The negative replica of the dental impression was changed into a positive one using the following technique: (1) “Select” option was used to select the dentulous areas, (2) “Invert” option was used to reverse the selection. (3) Then, “Delete” tool was used to delete all areas except teeth bearing areas. Finally, the positive replica of the digital dental model was get using the “flip normal” function of the program producing the Impression CBCT group (14) (Figure 2A).

Figure 1. : CBCT scan of impression

Virtual model preparation from casts

Stone casts were fabricated by pouring type IV stone (Shera stone, Werkstoff- Technologie). Each stone cast was scanned using the same CBCT machine and a laboratory scanner (Zirconzahn S600, Italy). The obtained DICOM files were also converted into STL files using the three-dimensional modelling software; Mimics software (Materialize Innovation Suite, Leuven, Belgium 22.0) after segmentation and thresholding at (300-3900 voxel value) in a new mask. These files were stored producing Cast CBCT group (Figure 2B).

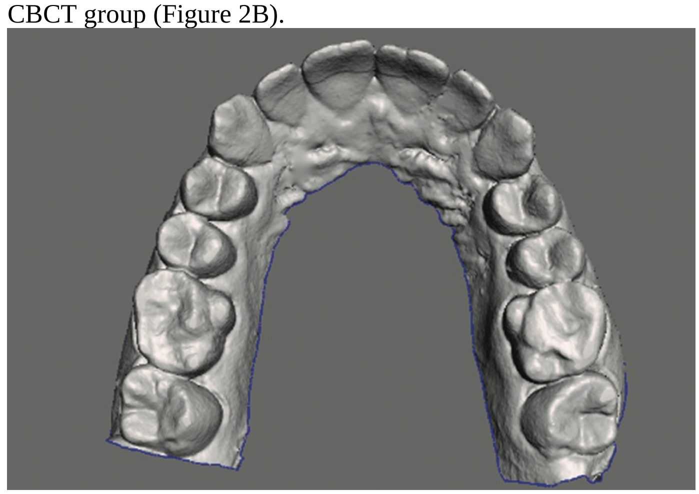

Figure 2A : Digital model obtained from CBCT scan of the impression

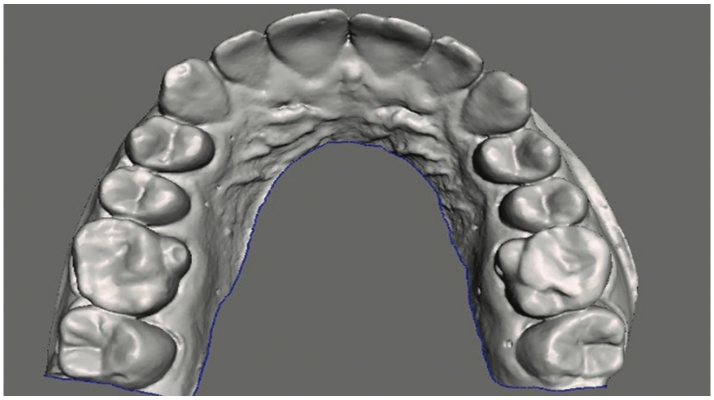

Figure 2B :. Digital model obtained from CBCT scan of the stone cast

Linear measures

All STL meshes were imported into the 3D modeling program (Autodesk Meshmixer 3.5; Autodesk Inc), each model was directed parallel to the grid provided by the software using the occlusal and labial views. Four linear measures were collected from each virtual model as follows; Canine to molar distance, Arch width (inter-canine (IC), and inter-molar (IM) distances, and Vertical dimension. The canine to molar distance was measured between the canine cusp tip and the mesio-buccal cusp tip of the first molar. The arch width was measured using the inter-canine distance, the line between the cusp tips of the bilateral canines and the inter-molar distance, the line between the mesio-buccal cusp tips of the bilateral first molars (Figure 3). The vertical measurement included the canine height, the distance from the gingival margin to the cusp tips of the corresponding canine. A digital caliper was used to measure the same stone models manually with accuracy of 0.01 mm. The caliper was set for 0 mm after each time. All measures were collected by the same researcher after three weeks for washing up.

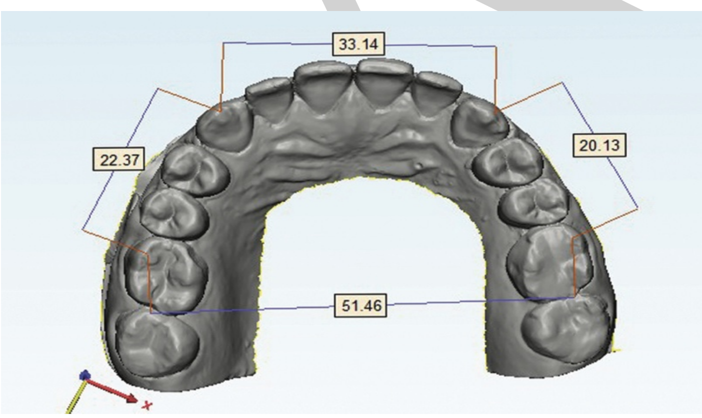

Figure 3 : Linear measures

Deviation analysis

To make a 3D comparison between the virtual models of each patient, each cast was scanned with a desktop scanner and the obtained model was set as a reference dataset and each other model was registered to this reference model. This 3D comparative analysis was done by a 3D modeling program 3-Matics software (Materialize Innovation Suite, Leuven, Belgium 12.0). Dimensional differences between each two models were calculated through "Analyze" tool present in the software and the mean deviation (measured in mm) was used to evaluate the correspondence of the superimposed virtual models. Color heat maps were obtained for visual qualitative assessments and a range of ± 0.5 mm (6 color sections) were designated. The green section represents the best match, the red section (0-0.5 mm) represents a positive deviation, and the blue section (-0.5- 0 mm) represents a negative deviation.

To conduct the statistical analysis, the measurement data were imported into IBM SPSS
software 19.0. The Kolmogorov-Smirnov test was used to determine the normality of the data
distribution. The significance of the obtained results was determined at the 5% level.

The intra-class correlation coefficient was used to assess intra-examiner reliability (ICC).

For normally distributed quantitative variables, the paired t-test was used to compare the groups,
ANOVA with repeated measures to compare more than two groups, and the Post Hoc test (Bonferroni
adjusted) for pairwise comparisons.

RESULTS

Intra-class correlation coefficient was found 0.98 for both Canine to molar distances and arch width dimensions and 0.96 for vertical dimensions showing that the intra examiner reliability for the linear measures was high. Comparison among groups based on linear measures is provided in table 1. In inter-canine width, Impression and Cast CBCT showed the least differences (-0.04 - -0.06 mm) respectively. Regarding the vertical dimension all groups showed minimal differences with no statistical significance (-0.02 and -0.07 mm). Pairwise Comparison between the studied groups based on linear measures is provided in Table 2.

Table (1): Comparison among groups based on linear measures

Measurement	Impression CBCT Mean diff.	Impression CBCT 95% C.I	Cast CBCT mean diff.	Cast CBCT 95% C.I
Canine –molar Arch Width	0.14*	0.04 – 0.25	0.17*	0.07 – 0.27
Inter canine	-0.04	-0.23 – 0.14	-0.06	-0.22 – 0.11
Inter molar	0.16*	0.01 – 0.31	0.15*	0.03 – 0.26
Vertical	-0.07	-0.34 - -0.01	-0.02	-0.12 – 0.07

*: Statistically significant at $p \leq 0.05$. diff; difference, CI: Confidence Interval

Table (2): Pairwise comparison of the groups based on linear measures

Canine –molar		**Impression CBCT**	1.000
	IC		
Arch Width		**Impression CBCT**	1.000
	IM	**Impression CBCT**	1.000
Vertical dimension			
		Impression CBCT	1.000

*: Statistically significant at $p \leq 0.05$. Sig. bet. periods was done using Post Hoc Test (adjusted Bonferroni)

In the current study, another comparison was performed that is 3D deviation analysis. The model produced by laser scan of the stone cast was fixed as reference mesh for deviation analysis. Each virtual model in each group was superimposed with this model. Mean deviation (in mm) was measured in the two groups, Cast CBCT group showed (-0.06 mm) deviation, followed by Impression CBCT showing (-0.09 mm) deviation. The deviation pattern was assessed visually by the color heat maps generated by the software. In Impression CBCT group higher deviation was detected at the inclined teeth surfaces as the incisal surfaces of the incisors and canines and buccal surfaces of the premolars (figure 4A). Whereas in Cast CBCT group the deviation pattern was homogenous across the entire model except the last molar teeth on both sides (figure 4B).

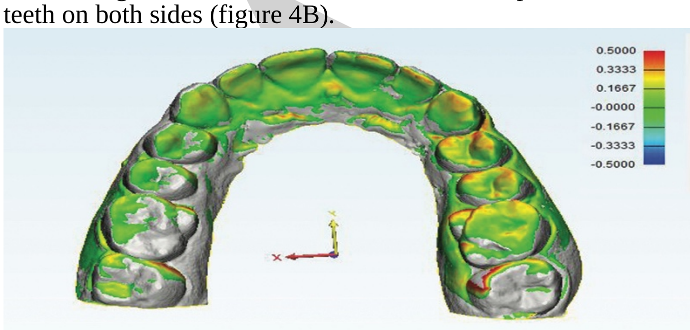

Figure 4A: Deviation analysis of Impression CBCT

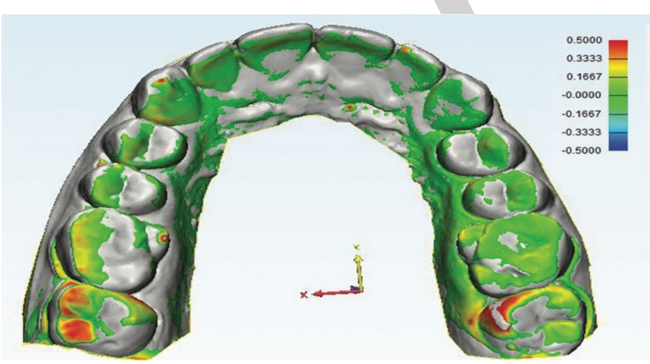

Figure 4B : Deviation analysis of Cast CBCT. The color map was set from -0.5 to 0.5 mm

DISCUSSION

Due to the increasing demand of computerized systems, a highly accurate method of virtual modelling has become mandatory. Therefore, the current research aimed to evaluate the validity and reliability of different techniques to obtain virtual model.

However, based on the findings of the present study, the null hypothesis that there was no significant difference between the reliability of 3D virtual models produced by various methods and the stone cast was rejected.

To the best of our knowledge, the current research was one of the few studies to be conducted in vivo to compare between these two techniques of virtual models fabrication (12,15,16).

Generally, in a systematic review (17, 18) it was proved that the mean differences between linear measures on stone and virtual models are within this range (0.04-0.4 mm) and considered it accepted clinically. Also, these results were supported by various studies that compared between measures in stone and virtual models where they stated a similar range of deviation as being clinically accepted (19-21). The present research showed the highest difference (0.16 mm) in IM distance in Impression CBCT group, this result is also considered clinically acceptable.

Previously, many studies evaluated the generation of study models from CBCT data wherethey used the patients DICOM to extract the teeth. Those models showed mean deviation higher than 1 mm for inter-canine and inter-molar dimensions (17, 22, 23). Moreover, this process violates thebasic concept “As Low As Reasonably Achievable” (ALARA), where the patient’s exposure to radiation has to be kept to the minimum possible dose. That’s why it is not preferred unless previously existing dataset was available or the patient already needs this imaging modality for any other purpose. While the use of CBCT to digitize impressions and casts do not expose the patient to any unnecessary radiation.

The reliability of virtual models produced by CBCT scan of impression and casts was assessed in some researches (12, 24). Wesemann et al (24) found that the digitalization of plaster models using the CBCT gave acceptable results while the digitalization of impressions showed insufficient or inaccurate findings. In the current reserach, we found more accuracy when using CBCT for both impressions and casts where CBCT of casts showed better results similarly. This enhanced accuracy could be interpreted by the use of different CBCT machine in the present study (Morita veraview x800) at higher spatial resolution (0.08 mm voxel size). The former research and other researches used 0.1 (12, 17, 22) and 0.2 mm voxel size (13).

In the research done by Park et al (12) virtual models by CBCT scanning of impressions and laser scanning of the plaster casts were compared. Most of the linear measurements have not showed a significant difference among the groups. These findings come in agreement with those of the present research.

Also, CBCT machines depend on volumetric scan techniques, while laboratory or laser-based scanners depend on scanning the surfaces only; therefore, the effect of irradiation angle is less in case of CBCT scanning. CBCT is advised in cases of crowding because it will not affect the raw scanned data (12).

Furthermore, it was observed that the models produced by CBCT scan have blocked undercuts. This is more useful in cases of STL models required to construct a surgical guide as the guide will seat properly on the patient's teeth with no interference.

Nevertheless, the surfaces of the models generated using CBCT scan either impression or stone casts were characterized by having a granular surface alike those obtained from the scanners. This phenomenon could be due to the difference in resolution between CBCT (80 µm) and the lab scanner (6 µm), and the automated system of the software of the lab scanners used to get a smooth surface after any scanning process. Moreover, CBCT has some drawbacks that decrease the image quality. One of them is the existence of noise, involving the scatter radiation (25).

The results of this research showed a negative deviation in IM distance. These results are in agreement with previous studies that performed linear measurements in Cone Beam CT (17, 22). This finding could be due to a generic effect in Cone Beam CT imaging that is the partial volume averaging (PVA) effect (26, 27). Matters that are located completely within a voxel are represented by a certain density for this voxel. Additionally, voxels that include two matters with two different densities (such as bone and air) have a mean density for those two matters. If this mean density is nearer to that of air, the other matter may be dropped by the software during the procedure of segmentation and conversion into STL mesh. This process leads to decreased volume of the object of this matter type. Improved threshold values can lead to more accurate findings.

In the current study, another comparison was performed that is 3D deviation analysis. It has been done in many recent researches (12, 16, 28-31). 3D measurements have more advantages than linear measurements such as the potency to measure at more points and to detect the focal areas of deviation (31). In laboratory researches a standard model with high known accuracy can be obtained from an industrial scanner and set as a reference control model, so that a comparison between it and the other groups under study could be easily done. However, in in-vivo studies this model cannot be obtained. To overcome this, a model with higher accuracy can be set as a reference one and compared with all other models (16). In the present research, the model generated by scanning of the cast with a desktop scanner was selected as the reference as it is the most widely used model in the clinical practice. 3D analysis provided similar results to that of the linear measurements. Cast CBCT group showed (0.06 mm) deviation, then Impression CBCT group showed higher deviation (0.09 mm).

The present study assessed accuracy of digital models in dentate patients, however, further studies are recommended in edentulous patients where few landmarks are available in the patient's mouth. Also, the effect of different exposure parameters and thresholding values on the accuracy of the obtained model has to be assessed.

CONCLUSIONS

Based on the results of the current research, the following was deduced: CBCT scanning of stone casts and impressions provided acceptable results but with reduced surface quality of the obtained mesh.

However, both methods can be used and implemented in the clinical dental setting.

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