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Evaluation of accuracy of intraoral scanners versus extra oral scanners in different dental arch measurements

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Abstract
Orthodontics has been influenced by new technologies in many areas. There is a shift toward digitization of patient's information and data. The purpose of this study was to compare the accuracy of intraoral scanner and extra oral scannersin different dental arch measurements. The sample size consisted of 44 dental stone models for patients who finished orthodontic treatment. For each subject two digital models were made, one digital model obtained from extra oral scanner and one digital model obtained from Intra oral scanner. An external examiner measured intermolar width, intercanine width, mesiodistal width of the first and second premolars on both left and right sides using ortho analyser 3shape programs from STL files. The same examiner evaluated the same measurements direct on the dental stone model using digital calliper. The results of the current study showed no statistically significant difference between the two tested models, digital models versus stone models.
Key words:*digital models, stone models, intraoral, extra oral, scanners*

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I. Introduction:

In the era of technology and computer sciences that invaded our daily life in a fast and continuous motion of development, that motion resulted in the increased usage of technologies in all levels of modern society. In many areas of health care; there is a shift toward digitization of patients' information and data. Orthodontics is no exception. Medical records, radiographs, digital models and photographs are just a few examples.Plaster models that is being traditionally used in orthodontics for evaluating patient's occlusal status have several limitations. They are subjected to physical and chemical damage and they wear when repeatedly measured. Models can also distort over time due to variation of humidity and temperature, moreover there is a problem concerning space to be stored in. (Sweeney and Taylor, 1950). Digital record storage has several advantages including: easy access, need for less physical space, ability to share information via the Internet with other professionals and with the patients (Marcel, 2001).

Digital models are produced by digitizing the oral structures, either directly or indirectly, with intra- or extra oral scanners. Orthodontists can examine intra arch and inter arch relationships digitally. Transverse relationships between maxillary and mandibular arches can be better evaluated when 3-dimensional models are viewed in occlusion in different perspectives in the screen. Digital models also have the advantage of allowing a virtualtreatment anda virtual setup (Hajeer and Millett, 2004).

There is uncertainty however, that these 2-dimensional computer screen systems can provide as much information as the hands-on 3-dimensional plaster models in terms of diagnosis, treatment planning, and evaluation. Digital models produced with extra oral scanners have been shown to be effective when compared to direct measurement on plaster models, with the differences between the approaches believed to be clinically acceptable(Stevens andFlores-Mir, 2006, Leifert and Leifert, 2009, Fleming and Marinho, 2011) Intraoral scanners have likewise been reported to produce valid and reliable digital models (Grünheid and McCarthy, 2011, Grünheid and McCarthy, 2014). There is Scarcity of data concerning the accuracy between the two different techniques. Hence this study was conducted to compare between the intra oral versus extra oral scanners for acquisition of 3D models accuracy.

II. Materials and Methods

The study was performed in the outpatient clinic of the Orthodontic Department in the Faculty of Oral and Dental Medicine Future University in Egypt. The recruited samples were obtained from records of patients in the Orthodontic Department in Faculty of Oral and Dental Medicine Future University in Egypt. This was a retrospective, analytical, cohort study which quantified the difference in accuracy of digital models obtained from intra oral scanner (3 shape, Trios 3 Mono Pod) versus extra oral scanner (3shape, E 2). The recruited sample was 44 dental stone models for patients who finished orthodontic treatment.

The inclusion criteria for the involved sample included the following: Dental models for patients that finished orthodontic treatment, Dental models for patients with fully erupted permanent teeth (not necessarily including the 3rd molar), Dental models for patients with Class I canine relationship, Sound dental models showing all the anatomical structures needed in the measurements for the study. Exclusion Criteria of the involved sample included: Dental models for patients who had carious, fractured or missing teeth, Dental models for patients with large restorations extended to proximal areas, Dental models for patients with morphological or structural teeth anomalies, Broken or worn dental models, Dental models for patients that treated with extraction.For each sample model, two digital models were obtained, 1: 3shape extra oral scanner digital orthodontic models (E2) and 2: 3shape intra oral scanner digital orthodontic models (Trios 3 Mono Pod).
Statistical analysis was used to compare the two methods. R Core Team (2019)

III. Results and Discussion

The main researcher and the external examiner measured intermolar width, inter-canine width, as well as mesiodistal width of the first and second premolars on both the maxillary and mandibular models using Ortho Analyzer 3shape program from STL files generated from the extra oral and intra oral scanners. The same examiner evaluated the same measurements direct on the dental models using digital calliper (Fig.1). The calliper was calibrated and accuracy confirmed before using by measuring a standardized ruler.Intermolar width (Figure 2A) was measured as the distance between the mesio-buccal cusp tips of the permanent first molars on the right and left sides while the Inter-canine width (Figure 2B) was measured as the distance between the crown tips of the permanent canines. Intermolar width and Inter-canine width were measured according to the methods used by Quimby and Vig (2004). Mesiodistal widths (Figure 2C) of each tooth were measured at their greatest width according to the methods used by Mullen and Martin (2007).

Fig.1:Digital calliper

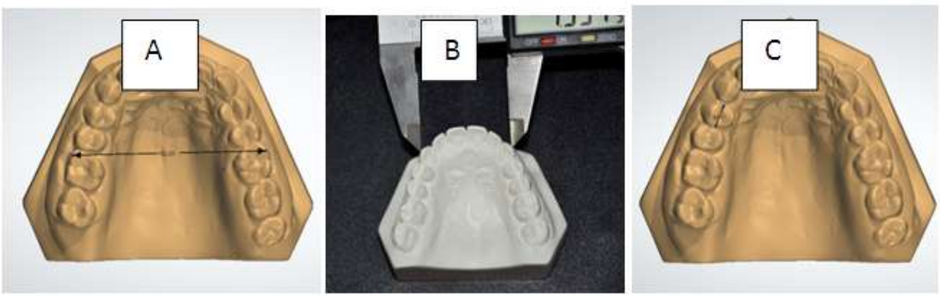

Fig 2, A: Intermolar width extra oral digital model measurement using ortho analyser software on digital models produced through extra oral scanning, B: Intercanine width stone model calliper measurement, C: Mesiodistal width of 1st premolarextra oral digital model measurement using ortho analyser software on digital models produced through extra oral scanning.

Difference between dental model and extra-oral scanner was determined. Mean, standard deviation (SD), Intra-class correlation coefficients and measurement error (ME) values for extra-oral scanner and dental model measurements (mm) were presented in Table 2 and Figures 3 and 4.Inter-molar distance (IM) measurements taken on the dental model (47.09±4.35) were significantly higher than those taken by extra-oral scanner (47.05±4.34) (p=0.013),the error value was small (ME=0.12) and the agreement was excellent (ICC=0.999). For Inter-canine distance (IC), there was no statisticallysignificant difference between different measurements (p=0.052), the error value was small (ME=0.05) and the agreement was excellent (ICC=1). Concerning the MD width of the right first premolar (R4), there was no statisticallysignificant difference between different measurements (p=0.249), the error value was small (ME=0.04) and the agreement was excellent (ICC=0.992). The MD width of the left first premolar (L4) measurements, taken on the dental model (5.99±0.45) were significantly higher than those taken by extra-oral scanner (5.98±0.45) (p=0.034), the error value was small (ME=0.04) and the agreement was excellent (ICC=0.993). The MD width of the right second premolar (R5) measurements, taken on the dental model (5.95±0.54) were significantly higher than those taken by extra-oral scanner (5.94±0.54) (p=0.028), the error value was small (ME=0.04) and the agreement was excellent (ICC=0.995). For the MD width of the right second premolar (L5), There was no statisticallysignificant difference between different measurements (p=0.091), the error value was small (ME=0.04) and the agreement was excellent (ICC=0.995).

Table 1: Mean and standard deviation (SD) values for extra-oral scanner and dental model measurements (mm)

Measurement		Mean±SD	Mean±SD of difference	D	ICC(95%CI)	p-value
IM	Dental model	47.09±4.35	0.05±0.17	0.12	0.999(0.999:0.999)	0.013*
	EO	47.05±4.34				
IC	Dental model	29.22±4.63	0.02±0.07	0.05	1(1:1)	0.052ns
	EO	29.20±4.63				
R4	Dental model	5.97±0.44	0.01±0.05	0.04	0.992(0.989:0.995)	0.249ns
	EO	5.96±0.45				
L4	Dental model	5.99±0.45	0.01±0.05	0.04	0.993(0.99:0.995)	0.034*
	EO	5.98±0.45				
R5	Dental model	5.95±0.54	0.01±0.06	0.04	0.995(0.992:0.996)	0.028*
	EO	5.94±0.54				
L5	Dental model	5.91±0.51	0.01±0.05	0.04	0.995(0.993:0.996)	0.091ns
	EO	5.90±0.51				

ME: measurementerror, ICC: Intra-class corrélation coefficients*; signifiant ($p \leq 0.05$) ns; non-signifiant ($p>0.05$)

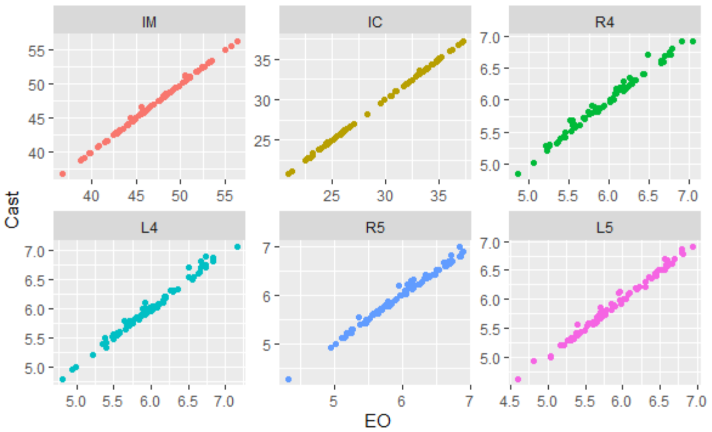

Figure 3: Scatter plot showing extra-oral scanner and dental model measurements (mm)

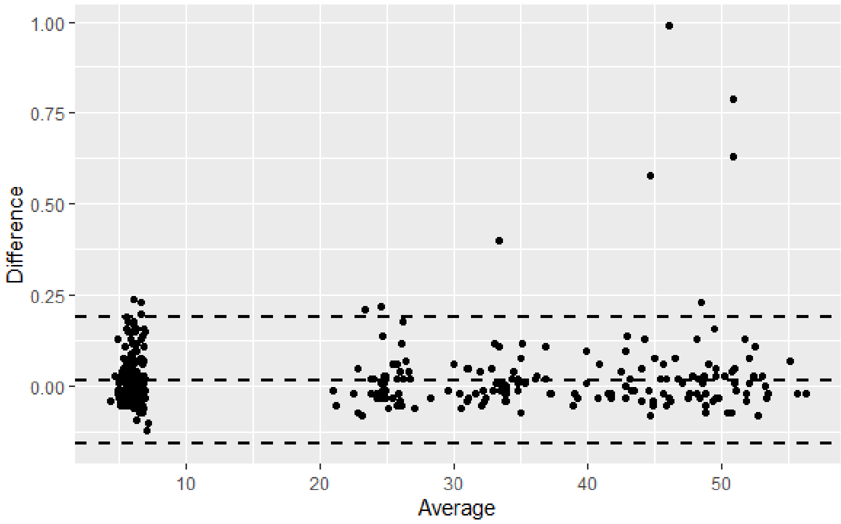

Figure 4: Bland-Altman plot of extra-oral scanner and dental model measurements (mm)

Difference between dental model and intra-oral scanner were recorded. Mean, standard deviation (SD), Intra-class correlation coefficients and measurement error (ME) values for intra-oral scanner and dental model measurements (mm) were presented in Table 2 and Figures 5 and 6.Inter-molar distance (IM) measurements taken on the dental model (47.09±4.35) were significantly higher than those taken by intra-oral scanner (47.05±4.34) (p=0.029),the error value was small (ME=0.13) and the agreement was excellent (ICC=0.999). For Inter-canine distance (IC), there was no statisticallysignificant difference between different measurements (p=0.752), the error value was small (ME=0.12) and the agreement was excellent (ICC=0.999). The MD width of the right first premolar (R4) measurements taken on the dental model (5.97±0.44) were significantly higher than those taken by intra-oral scanner (5.95±0.45) (p=0.036), the error value was small (ME=0.07) and the agreement was excellent (ICC=0.977). The MD width of the left first premolar (L4) measurements taken on the dental model (5.99±0.45) were significantly higher than those taken by intra-oral scanner (5.97±0.45) (p=0.022), the error value was small (ME=0.06) and the agreement was excellent (ICC=0.985). The MD width of the right second premolar (R5) measurements taken on the dental model (5.95±0.54) were significantly higher than those taken by intra-oral scanner (5.92±0.53) (p=0.012), the error value was small (ME=0.10) and the agreement was excellent (ICC=0.967). For the MD width of the right second premolar (L5), there was no statisticallysignificant difference between different measurements (p=0.226), the error value was small (ME=0.05) and the agreement was excellent (ICC=0.989).

Table 2: Mean and standard deviation (SD) values for intra-oral scanner and dental model measurements (mm)

Measurement		Mean±SD	Difference	D	ICC(95%CI)	p-value
IM	Dental model	47.09±4.35	0.04±0.18	0.13	0.999(0.999:0.999)	0.029*
	IO	47.05±4.34				
IC	Dental model	29.22±4.63	0.01±0.17	0.12	0.999(0.999:1)	0.752ns
	IO	29.21±4.62				
R4	Dental model	5.97±0.44	0.02±0.1	0.07	0.977(0.968:0.984)	0.036*
	IO	5.95±0.45				
L4	Dentall model	5.99±0.45	0.02±0.08	0.06	0.985(0.979:0.989)	0.022*
	IO	5.97±0.45				
R5	Dental model	5.95±0.54	0.04±0.14	0.1	0.967(0.954:0.977)	0.012*
	IO	5.92±0.53				

L5	Dental model	5.91±0.51	0.01±0.08	0.05	0.989(0.984:0.992)	0.226ns
	IO	5.90±0.51				

ME: measurement error, ICC: Intra-class correlation coefficients. * : significant at p ≤ 0.05, ns : non-significant at p>0.05.

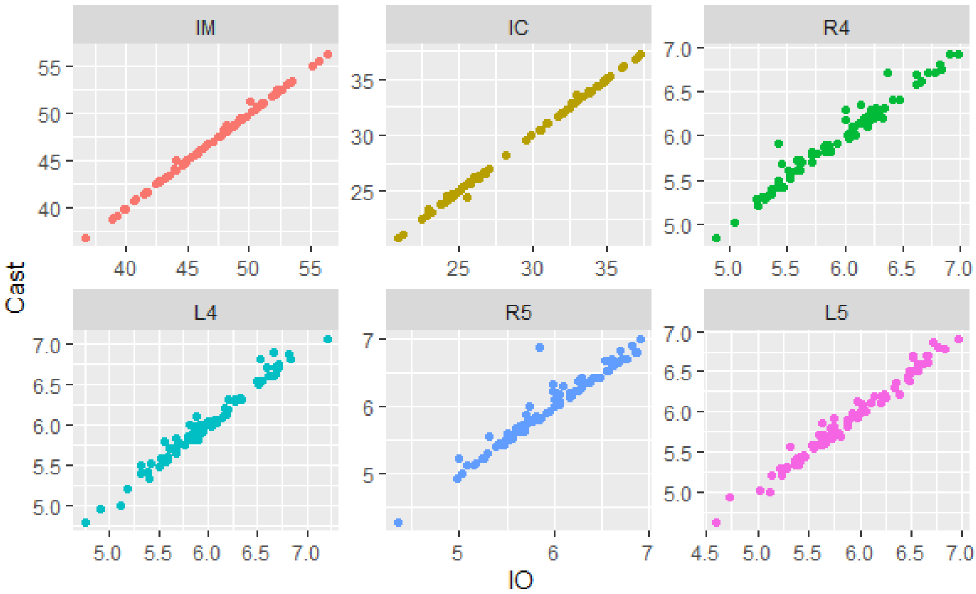

Figure 5: Scatter plot showing intra-oral scanner and dental model measurements (mm)

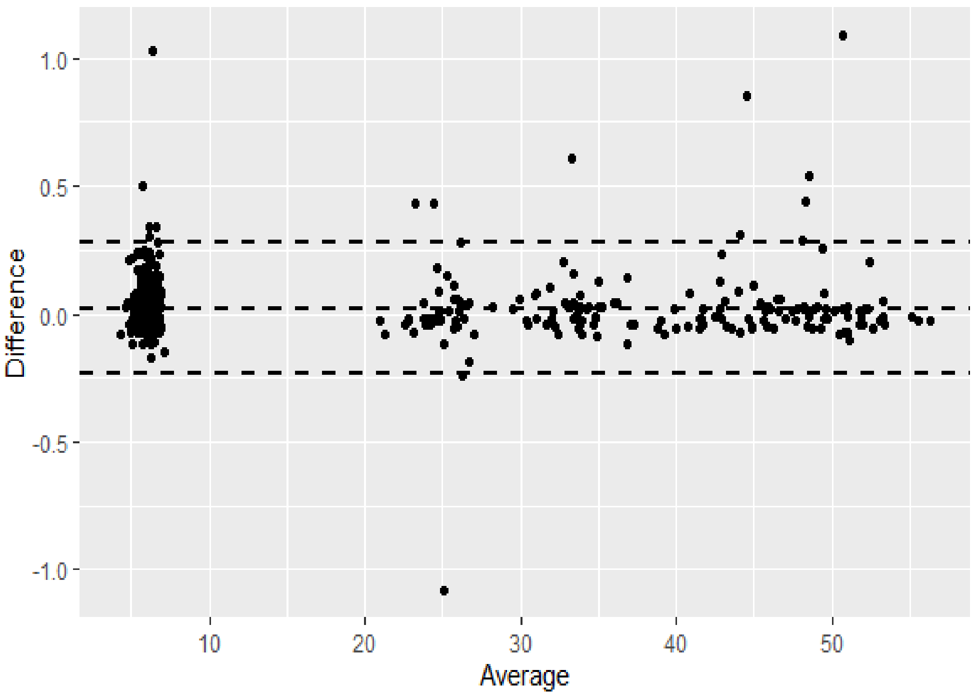

Figure 6: Bland-Altman plot of intra-oral scanner and dental model measurements (mm)

Difference between Intraoral and Extraoral scanners measurements was recorded. Mean and standard deviation (SD) value for the difference between dental model and scanners' measurements (mm) were presented in Table 3 and Figures 7 and 8. For Inter-molar distance (IM) and Inter-canine distance (IC), there was no statisticallysignificant difference between the measurement discrepancy recorded with both scanners (p=0.854and0.543, respectively). For MD width of the right first premolar (R4), the difference measured with intra-oral scanner (0.02±0.1) was significantly higher than that found with extra-oral scanner (0.01±0.05) (p=0.030). For MD width of the left first premolar,L4 MD width of the right second premolar (R5) and MD width of the right second premolar (L5), there was no statisticallysignificant difference between the measurement discrepancy recorded with both scanners (p=0.160, p=0.072 and p=0.922, respectively).

Table 3: Mean and standard deviation (SD) values for the difference between dental model and scanners' measurements (mm)

Measurement	Mean±SD	Mean difference±SD	p-value
IM	0.05±0.17	0.04±0.18	0.854ns
IC	0.02±0.07	0.01±0.17	0.543ns
R4	0.01±0.05	0.02±0.1	0.030*
L4	0.01±0.05	0.02±0.08	0.160ns
R5	0.01±0.06	0.04±0.14	0.072ns
L5	0.01±0.05	0.01±0.08	0.922ns

*; significant ($p \leq 0.05$) ns; non-significant ($p>0.05$)

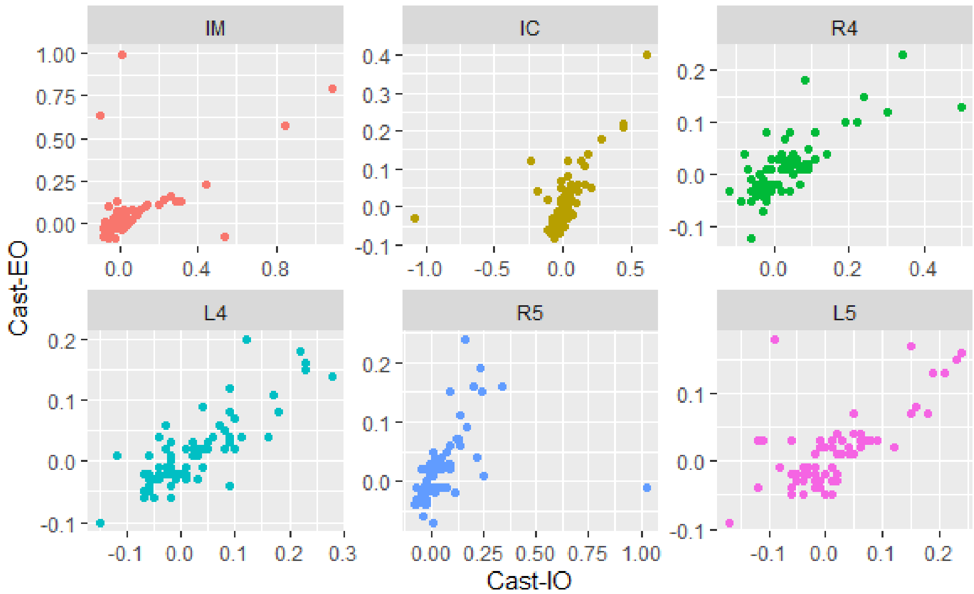

Figure 7: Scatter plot showing the difference between dental model and scanners' measurements (mm)

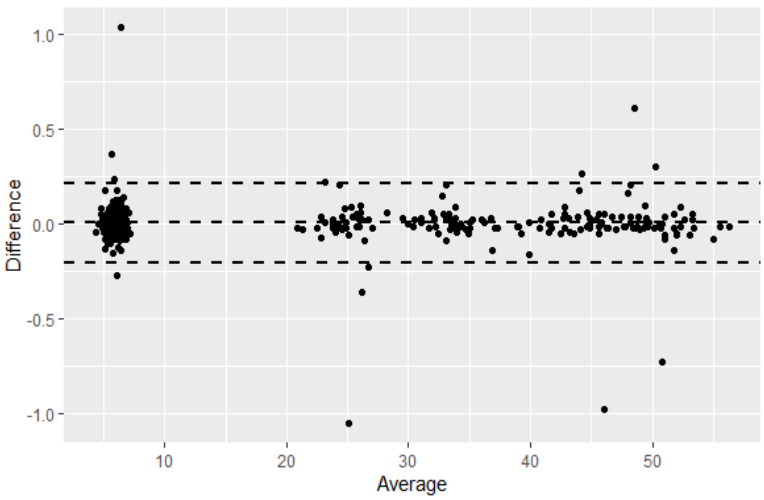

Figure 8: Bland-Altman plot of extra and intra-oral measurements (mm)

Numerical data were explored for normality by checking the data distribution, calculating the mean and median values and using Kolmogorov-Smirnov and Shapiro-Wilk tests. Data showed parametric distribution and were presented as mean, standard deviation (SD) values. Inter and intra-rater agreements were analyzed using intra-class correlation coefficient (ICC) and measurement error (ME) values. Differences between scanners and the actual dental model measurements were assessed using paired-t test. The significance level was set at $p \leq 0.05$ within all tests. Statistical analysis was performed with R statistical analysis software

Difference between dental model and extra-oral scanner were detected. Mean, standard deviation (SD), Intra-class correlation coefficients and measurement error (ME) values for extra-oral scanner and dental model measurements (mm) were presented in Table (2) and Figures 5 and 6. For Inter-molar distance (IM), measurements taken on the dental model (47.09±4.35) were significantly higher than those taken by extra-oral scanner (47.05±4.34) (p=0.013),the error value was small (ME=0.12) and the agreement was excellent (ICC=0.999). For Inter-canine distance (IC), there was no statisticallysignificant difference between different measurements (p=0.052), the error value was small (ME=0.05) and the agreement was excellent (ICC=1). For MD width of the right first premolar (R4), there was no statisticallysignificant difference between different measurements (p=0.249), the error value was small (ME=0.04) and the agreement was excellent (ICC=0.992). For MD width of the left first premolar (L4), measurements taken on the dental model (5.99±0.45) were significantly higher than those taken by extra-oral scanner (5.98±0.45) (p=0.034), the error value was small (ME=0.04) and the agreement was excellent (ICC=0.993).MD width of the right second premolar (R5) measurements taken on the dental model (5.95±0.54) were significantly higher than those taken by extra-oral scanner (5.94±0.54) (p=0.028), the error value was small (ME=0.04) and the agreement was excellent (ICC=0.995). For the MD width of the right second premolar (L5), there was no statisticallysignificant difference between different measurements (p=0.091), the error value was small (ME=0.04) and the agreement was excellent (ICC=0.995).

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4-MD width of the left first premolar (L4):

Measurements taken on the dental model (5.99±0.45) were significantly higher than those taken by intra-oral scanner (5.97±0.45) (p=0.022), the error value was small (ME=0.06) and the agreement was excellent (ICC=0.985). For MD width of the right second premolar (R5), the measurements taken on the dental model (5.95±0.54) were significantly higher than those taken by intra-oral scanner (5.92±0.53) (p=0.012), the error value was small (ME=0.10) and the agreement was excellent (ICC=0.967). For MD width of the right second premolar (L5), there was no statisticallysignificant difference between different measurements (p=0.226), the error value was small (ME=0.05) and the agreement was excellent (ICC=0.989).

Difference between Intraoral and Extraoral scanners' measurements was recorded. Mean and standard deviation value for the difference between dental model and scanners' measurements (mm) were presented in Table 4 and Figures 9 and 10. For Inter-molar distance (IM) and Inter-canine distance (IC), there was no statisticallysignificant difference between the measurement discrepancy recorded with both scanners (p=0.854 and p=0.543, respectively). For MD width of the right first premolar (R4), the difference measured with intra-oral scanner (0.02±0.1) was significantly higher than that found with extra-oral scanner (0.01±0.05) where p=0.030. For MD width of the left first premolar (L4), MD width of the right second premolar (R5) and MD width of the right second premolar (L5), there was no statisticallysignificant difference between the measurement discrepancy recorded with both scanners (p=0.160, 0.072 and 0.922, respectively).

In most studies cited in the literature review where precision, validity, reliability and reproducibility of linear dental measurements were tested on digital models acquired from scans of alginate impressions and plaster models; the findings showed that the obtained digital models were valid, accurate and reproducible for diagnostic purposes (Naidu et al., 2013, Santoro et al., 2003, Rheude et al., 2005). The literature suggests that little statistical and/or clinical differences exist between the resultant digital models with respect to utilizing the models for treatment planning.

The sample size was said to be 88 models, and it was determined after reviewing the value in literature. Quimby et al.(2004) used similar sample size; other authors used smaller sample size ranging from 15-30 subjects (Jacobet al., 2015, Stevens et al., 2006and Lifert et al., 2009). The models included the patients who finished orthodontic treatment with Class I canine relationship. Dental stone models showing all the anatomical structures needed for the measurements in the study. Those criteria allowed the measurements in the study to be practical and accurate, compared to Quimby et al. (2004)and Horton et al. (2010). They used various types of malocclusions, spacing and crowding subjects.

In the present study, plaster model and digital models obtained from extra oral scanner (3shape E2) and intra oral scanner digital models (Trios 3 Mono) were compared for 6 measurements including inter-molar width, inter-canine width, first and second premolar on right and left side. Similarly,Rosseto et al., (2009) compared four measurements (inter-canine and inter-molar width), while Jacob et al. (2015) compared five measurements (inter-molar, inter-canine, Posterior arch length, pre-molar width and canine height).

There were two main characteristics that made our study noteworthy. First, its sample size, second, measurements were done on stone models of treated cases. The case that could simplify the measurements method due to the elimination of malocclusion could make the measurement further challenging. Each of the two scanners produced accurate representations, with no consistent pattern of systematic errors.When comparing digital models obtained from the extra oral and intra oral scanning methods to direct dental model measurement the results of the study showed that there was no statistical significant difference between the two methods (Considerably small relative Dahlberg Error less than 1%) concerning all measurements, yet almost all the mean differences showed positive values indicating that the digital models obtained through extra oral scanner measurements undervalued the dental stoned model dimensions except in the lower inter canine width that was larger when measured on the digital models of intra oral scanner than the dental stone model value. Those results were consonant to Jacob et al. (2015) when they compared the extra oral and intra oral scanners to direct measurements on the dried human mandible. However, they found a statistically significant difference in arch length and canine height values (0.159 mm) and (0.363 mm) respectively. Those values were smaller in the digital models of extra oral method than the direct dental model measurements which agree with Jacob et al.(2015) study.In the current study the mean difference of the measurements range from (0.01-0.5 mm) which could be considered clinically insignificant according to Schirmer et al. (1997) who reported that Measurement differences less than 0.20 mm have been suggested to be clinically acceptable If the individual has been adequately calibrated and maintains the same landmark definitions, systematic intra observer differences should not be expected to occur. The two scanners were also highly reliable, with ICCs ranging from 0.990 to 0.999according to considering that reliability coefficients above 0.75 have been considered to be excellent, the substantially higher ICCs obtained in the present study indicate excellent reproducibility.(M¨ormann WH.2006)

When comparing the two methods of scanning to each other it was found that digital models obtained through intra oral scanner produced larger random errors than the digital models obtained through extra oral scanner except in lower inter molar width, which was the opposite to the findings of Jacob et al. (2015) who found the errors in the extra oral scanner larger than intra oral scanner. According to the above results of the study, we found that both of the two scanners produced accurate representations, with no consistent pattern of systematic errors.For the dental practitioner, the potential benefits of using an intraoral scanner may include Simplification the tasks associated with the taking of conventional impressions are no longer required. Tray selection, material mixing, cleaning and plaster pouring are all made redundant and the possibility of impression failures and model retakes is eliminated entirely. The potential for improved accuracy assuming that the digital impression has been correctly obtained, material shrinkage during the curing of impression materials is removed, there can be no air bubbles, no distortion due to tray movement and no risk of there being insufficient material in the tray or inadequate adhesive. Patient comfort: The reaction from patients has been decidedly positive. The use of an intraoral scanner can be advantageous for patients with a pronounced gag reflex or with a cleft lip and palate, and for those who are at risk of aspiration or respiratory distress during the taking of a traditional dental impression.On the other hand, the only advantage of extraoral scanners versus the intraoral scanners is that there is no need to be available at the dental clinic unlike the intraoral scanner. Thus, this study does not evaluate the Intraoral scanner intraorally, but merely investigates its manufacturer's accuracy by testing it extra orally. This study needs to be substantiated with a further study to evaluate its efficiency in vivo under the challenging in intraoral limitations of saliva, large size of the scanner tip, amalgam restorations, arch curvature.

IV. Conclusion:

Both intra oral and extra oral scanning methods were reliable on producing accurate digital models and there was no statistically significant difference between measurements obtained on digital models by intra oral and extra oral scanners versus those done on stone models. Using measuring software's facilitated dental model analysis measurement as compared to digital calliper.

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