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ORIGINAL ARTICLE

COMPARISON OF DENTAL DIMENSIONS IN MODELS DEVELOPED WITH DIGITAL PROCEDURES AND PLASTER MODELS

Comparación de dimensiones dentales en modelos desarrollados con procedimientos digitales y modelos en yeso

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ABSTRACT

Aim: This study aimed to collect evidence on the validity and reliability of measurements obtained from digital impression techniques.

Materials and Methods: This comparative study was conducted on 31 patients. Intraoral scanner was applied to all patients. For each patient, an alginate impression of the upper maxilla was taken and later the 3D digital model was extracted by dental cone-beam computed tomography (CBCT). For preparation of plaster models, alginate impressions were taken and immediately poured with dental stone. In the next stage, a comparison was performed among the intraoral scanner, CBCT, and plaster models in terms of tooth size, dental width, and intra-arch dimensions.

Results: Measuring tooth size and intra-arch dimensions in digital images obtained from intraoral scanner and CBCT were in most cases lower than the results obtained in the plaster models but the differences between digital techniques and plaster models are not clinically noticeable.

Conclusions: Digital systems including intraoral scanner and CBCT are acceptable for clinical use in terms of accuracy.

Keywords: Cone Beam Computed Tomography; Intraoral scanning; Plaster casts; Alginates; Orthodontics; Methods.

RESUMEN

Objetivo: Este estudio tuvo como objetivo recopilar evidencia sobre la validez y confiabilidad de las mediciones obtenidas a partir de técnicas de impresión digital.

Materiales y Métodos: Este estudio comparativo se realizó en 31 pacientes. A todos los pacientes se les aplicó escáner intraoral. Para cada paciente, se tomó una impresión de alginato del maxilar superior y posteriormente se extrajo el modelo digital 3D mediante Tomografía computarizada de haz cónico (CBCT) dental. Para la preparación de los modelos de yeso se tomaron impresiones de alginato y se vertieron inmediatamente con yeso dental. En la siguiente etapa, se realizó una comparación entre el escáner intraoral, CBCT y los modelos de yeso en términos de tamaño de diente, ancho dental y dimensiones intraarcada.

Discusión: Se encontró que la apariencia microscópica de las células fusiformes era comparable en ambos grupos. Los resultados de la citometría de flujo demostraron expresiones comparables en ambos grupos, siendo las muestras positivas para CD90, CD73, CD10[5], HLA ABC y negativas para CD34, CD45 y HLA DR. Hubo variaciones en la expresión de los marcadores cuando se evaluaron los potenciales de diferenciación.

Conclusión: Los sistemas digitales como el escáner intraoral y el CBCT son aceptables para uso clínico en términos de precisión.

Palabras Clave: Tomografía Computarizada de Haz Cónico; Escáner intraoral; Moldes de yeso; Alginatos; Ortodoncia; Métodos.

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INTRODUCTION

The growing variety of clinical aspects of malocclusions has led to the emergence of new methods for diagnosis and treatment.[1]

There are different approaches to determine the need for orthodontic treatment, including the patient's dental records, clinical examination, plaster models made of the patient's dental model, and X-ray imaging.

Diagnosis in orthodontic treatment requires accurate intraoral measurements. Evaluation of the space and size of the teeth, as well as the measure-ment of tooth size-arch length discrepancy are the most important components of the diagnostic process in the patients who underwent orthodontic treatment.[2]

Traditionally, mesiodistal dimensions of the teeth are measured on a dental cast using a calibrated compass or vernier caliper; however, this method is time-consuming.[3]

Plaster casts are known as the gold standard for diagnosis, diagnosis and treatment planning in orthodontics.[4] It has been observed that plaster casts present precise and reliable information about patients' dental arches, position of teeth and their dimensions.[5] The plaster models also have the advantage of being inexpensive. Conversely, plaster models have disadvantages including storage costs, time-consuming procedure, potential for breakage, their heavy weight and difficulties in sharing their data with other professionals involved in the patients' care.[6]

Due to the complications followed by using the plaster models, some methods, including photocopying, photography, and hologram methods, as well as digitization of points on the cast or its images are introduced to perform space analysis.[7] Digital techniques have been introduced to facilitate the preparation of the dental models, accelerate the process of diagnosis and treatment plan, and predict the process of treatment and prognosis to measure the dental space. The most successful systems were based on the use of optical methods and laser cast scanning.[8,9]

Storage, processing, and browsing of information are easily possible in the digital techniques, and there is no need to use impression materials. If one or more patients need to consult with other specialists regarding using this technology, the models are easily shared and discussed accompanied by various analyzes.

Furthermore, despite the high speed of development of the-se technologies, if it is necessary, it is possible to convert patients' digital models into physical casts by using a 3D printer.[10]

Intraoral scanning using an intraoral scanner is one way to obtain digital models and analyze the inside of the oral cavity directly without impression and pouring. Intraoral scanners have several advantages including reduced patient discomfort, time efficiency, simplification of clinical procedures, and the benefit of capturing and storing highly accurate information.[11,12]

Moreover, the complications, such as the expansion of casting mold, shrinkage of molding materials, or shape change when taking it out of the mouth, are solved using an intraoral scanner. However, intraoral scanning may lead to errors when measuring the dental arch due to the cumulative effect of registration errors.[13] The clinical advantage of the oral scanner is the less discomfort of the patient who does not tolerate the classic impressions in alginate.[14]

Although time-saving is one of the main advantages of the intraoral scans, it could be more time consuming if it is applied by inexperienced practitioners; accordingly, the practitioner's level of familiarity with the scanning system directly

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affects the time needed to complete the scans.[15]
In the late 1990s, Cone-beam computed tomography (CBCT), a relatively newer technology, was introduced in dentistry. CBCT has become popular in orthodontics as it provides a 3D image of the craniofacial complex and its multidimensional reconstruction of the tooth-bone complex provides a comprehensive view on which the reliable measurements can be made.[16]

With the development of digital methods and intraoral scanners, the evaluation of the accuracy and reproducibility of measurements obtained from these techniques should be conducted. Moreover, as a result of the increasing emphasis on evidence-based orthodontics, the accuracy and reproducibility of different methods should be evaluated in order to make correct clinical decisions. In this regard, the aim of this study was to investigate the validity and reliability of dental width and intra-arch dimension measurements obtained from intraoral scanner and CBCT and comparing them with the original plaster model.

MATERIALS AND METHODS

This comparative study was conducted on the patients who referred to the Orthodontic Department of School of Dentistry in Mashhad, Mashhad, Iran for fixed orthodontic treatment during 2018-2019.

Study Design

According to a previously conducted study,[15] the sample size was determined at 18 cases using α=0.05 and β=0.5. However, to increase the power test and consi-dering the sample attrition, it was increased to 31 individuals.
The samples were randomly selected from the patients referred to the Orthodontic Department of School of Dentistry of School of Dentistry in Mashhad, Mashhad, Iran.
Eventually, 31 patients with permanent dentition who were candidates for fixed orthodontic treatment were included in this study.

All patients (31 maxillary arches) were subjected to an intraoral scanner. For each patient, alginate (Marlic Medical Industries Co. Iran) impression of upper maxilla was taken and later the 3D digital model was extracted by dental CBCT (Planmeca Promax 3DMax-Helsinky Finland). For preparation of plaster models, alginate set (Marlic Medical Industries Co. Iran) impressions were taken and immediately poured with plaster. Digital images obtained from an intraoral scanner (Planmeca PlanScan; Planmeca, Helsinki, Finland) and CBCT were transferred to Planmeca Romexis 3D Ortho Studio dental software (Planmeca, Helsinki, Finland). Measurements were done in digital methods on their images (Figure 1) and point by point. The reference points were the same in all three methods.

A digital vernier caliper was also utilized to eliminate the possibility of the parallel error. The indexes measured in the plaster and digital models included the tooth size (width of the mesiodistal dimension) and inter first molar width, as well as intra-arch dimensions (*i.e.*, intermolars width, inter-canine dimensions, and arch length). Measurements were performed directly on the dental casts and digital models. The measurements were made on these physical models with the help of a digital vernier caliper. Some linear measurements were taken from each cast, including arch length and width.

Finally, the measurement accuracy of digital models was compared with plaster models. The measurements were performed by a trained dental student. The intraclass correlation coefficient (ICC) was used to determine the reliability of the clinical measurement (manual measurement). To assess the reliability, 10 patients were randomly selected, and the same person who performed the main measurements performed manual measurements related to their cast. Similarly, 10 patients were randomly selected and manual measurements of the casts were performed for them by another person. The reliability of the measured dimensions was calculated and it showed no significant differences.

Statistical Analysis

The data were analyzed in SPSS software (version 22). Moreover, the quantitative and qualitative variables were described through Mean±SD as well as frequency and percentage, respectively. Data normality was assessed using the Shapiro-Wilk test, and the Friedman test and the Wilcoxon test were applied for statistical analyses. $p<0.05$ was considered statistically significant.

Ethical considerations

The protocol of present study was approved by the Research Ethics Committee of Mashhad University of Medical Sciences (Ethical code: IR.mums.sd.REC.1394.314) on 7 March 2018.

Before the study, research procedures and objectives were explained to the patients, and informed consent was obtained from them. Moreover, the patients were assured that they could withdraw from the study at any time.

RESULTS

Table 1 tabulates the comparison results of tooth size in right and left sides based on these three approaches. The results of the Friedman test showed a significant difference among the three approaches regarding the size of the right maxillary second premolar (p=0.02).

According to the results of two-by-two comparisons (Wilcoxon test), the size of the right second premolar measured by the intraoral scanner was significantly less than that measured by the CBCT, however there was no significant differences between the plaster models with CBCT and intraoral scanner (Table 2).

In addition, no significant difference was observed among three methods regarding the size of the right first molar, right canine, and right lateral incisor. Three methods showed significant differences in terms of the size of the left maxillary second premolar (p=0.004), left canine (p<0.001), left central incisor (p<0.001), and left lateral incisor (p=0.002).

The two-by-two comparison (Wilcoxon test) showed that the sizes of the left maxillary second premolar, left canine, central, and left lateral incisor measured by the intraoral scanner and CBCT were significantly less than the actual sizes measured by plaster models (Table 2). The sizes of the left second premolar and left canine measured by intraoral scanner were significantly less than the actual size measured by CBCT; however, there was no significant difference between these two methods in the sizes of the left lateral and left central.

Table 3 summarizes the comparison results of inter-arch dimensions measured by CBCT, intraoral scanner, and plaster models. The comparison of inter-arch dimensions by Friedman test showed no significant difference among the three methods in terms of inter-first molar width. However, a significant difference was observed among these approaches regarding the width of the inter-canine (p=0.004). The comparison result of arch length revealed a significant difference among the three approaches (p<0.001). The two-by-two comparisons (Wilcoxon test) showed that the arch length and width of the inter-canine measured by the intraoral scanner were

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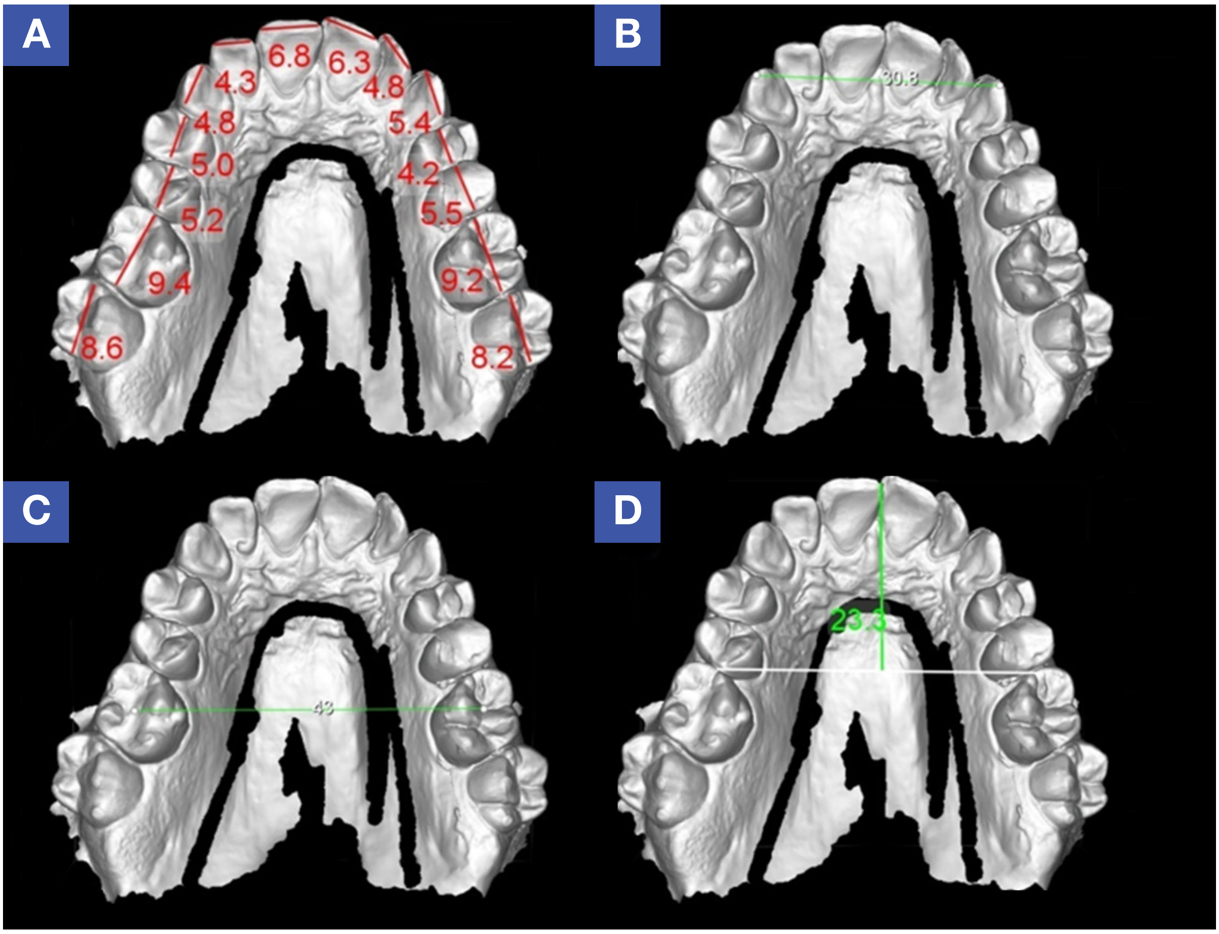
Figure 1. Measurements on images obtained using an oral scanner.



A. Mesiodistal dimension. **B.** inter-canine. **C.** First inter molar. **D.** Arch length.

Table 1. Comparison of the tooth size based on the side and type of tooth using three approaches.

	Variables	Plaster Models		Intraoral Scanner		CBCT		*p*-value
		Mean (mm)	SD	Mean (mm)	SD	Mean (mm)	SD	
Right teeth	First molar	10.35	0.52	10.3	0.52	10.3	0.5	0.58
	Second Premolar	6.65	0.47	6.59	0.39	6.76	0.75	0.02
	First Premolar	4.53	3.2	4.45	3.22	4.44	3.21	0.045
	Canine	7.3	2.02	7.46	1.52	7.44	1.53	0.19
	Lateral	6.84	0.63	6.83	0.67	6.87	0.69	0.76
	Central	8.69	0.51	8.56	0.49	8.54	0.67	0.07
Left teeth	First molar	10.22	0.65	10.17	0.55	10.19	0.55	0.06
	Second Premolar	6.8	0.54	6.71	0.46	6.74	0.48	0.004
	First Premolar	4.07	3.31	4.2	3.27	4.21	3.27	0.81
	Canine	7.23	1.99	7.07	1.97	7.14	1.99	<0.001
	Lateral	6.94	0.47	6.82	0.41	6.88	0.5	0.002
	Central	8.76	0.54	8.61	0.57	8.59	0.67	<0.001

SD. Standard deviation. **CBCT.** Cone-beam computed tomography.

Table 2. Results of the two-by-two comparison (Wilcoxon test) of the tooth size .

Side	Tooth	(I) Group	(J) Group	*p*-value
Right	Second Premolar	Plaster Models	Intraoral Scanner	0.066
		Intraoral Scanner	CBCT	0.446
			CBCT	0.03
Left	Second Premolar	Plaster Models	Intraoral Scanner	0.002
		Intraoral Scanner	CBCT	0.005
			CBCT	0.046
Left	Canine	Plaster Models	Intraoral Scanner	<0.001
		Intraoral Scanner	CBCT	0.007
			CBCT	0.005
Left	Lateral	Plaster Models	Intraoral Scanner	<0.001
		Intraoral Scanner	CBCT	<0.001
			CBCT	0.083
Left	Central	Plaster Models	Intraoral Scanner	<0.001
		Intraoral Scanner	CBCT	0.001
			CBCT	0.333

Table 3. Comparison of inter-arch dimensions measured by the intraoral scanner, Cone-Beam Computed Tomography and plaster models.

Inter-arch dimensions	CBCT		Intraoral scanner		Plaster models		*p*-value
	Mean (cm)	SD	Mean (cm)	SD	Mean (cm)	SD	
Width of the inter-canine (n=31)	3.16	0.88	3.12	0.86	3.15	0.88	0.004
Width of the first inter molar (n=31)	4.43	0.33	4.43	0.32	4.43	0.32	0.98
Arch length(n=31)	2.30	0.33	2.23	0.34	2.31	0.3	<0.001

SD. Standard deviation. **CBCT.** Cone-beam computed tomography.

Table 4. Results of the two-by-two comparison (Wilcoxon test) of the tooth size.

Inter-arch dimensions	(I) Group	(J) Group	*p*-value
Width of the inter-canine	Plaster Models	Intraoral Scanner	0.031
	Intraoral Scanner	CBCT	0.770
		CBCT	0.002
Arch length	Plaster Models	Intraoral Scanner	<0.001
	Intraoral Scanner	CBCT	0.028
		CBCT	<0.001

CBCT. Cone-beam computed tomography.

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significantly less than that measured by the plaster models; nonetheless, there was no difference between the plaster models and CBCT in measurement of the width of the inter-canine (Table 4).

The arch length and width of the inter-canine measured by intraoral scanner was lower than CBCT. In addition, the arch length measured by plaster models was significantly lower than CBCT.

DISCUSSION

Study models represent fundamental and crucial elements for diagnosing and planning treatment in orthodontic cases, and they have transitioned to digital formats over the past decade.[17] The plaster models have been used for many years as a standard approach to measuring the intraoral dimensions. They were utilized as the gold standard in our study. However, possible dimensional changes in impression material and the fabrication process of the plaster model may lead to manipulation of actual dentition measurements.[18,19] Some degree of interpretation inaccuracy is reported in the measurements obtained by plaster. In digital models with dedicated software, the problem of point identification could be decreased due to its possibility of enlarging the images.[20]

Our results showed that measuring tooth size and intra-arch dimensions in digital images obtained from intraoral scanner and CBCT were in most cases lower than the results obtained in the plaster models but the differences between digital techniques and plaster models are not clinically noticeable. It should be noted that the acceptable clinical value for the difference in the total maxillary or mandibular tooth materials, arch length, and transverse dimension measurements must be not > 1.5 mm.[21,22]

In our study, all of the differences were smaller than 1.5mm. Hence, the results support the clinical application of these methods. Many studies have confirmed the accuracy and reproducibility of intraoral scanners and CBCT methods regarding the speed enhancement and methods showed differences regarding the widths of the intercanine and arch length.

The obtained results of a similar study performed on the distances measured by digital and plaster models showed no difference among them in this regard.[15,20] Kumar *et al.,*[23] showed no difference among computer-aided design (CAD)/computer-aided manufacturing (CAM), CBCT, and plaster models in terms of tooth-width measurements, anterior teeth, and overall Bolton ratio. They suggested both CBCT and CAD/CAM as alternative models for plaster models. Other similar studies showed no difference between plaster and digital models in terms of the reliability of tooth size and space analysis measurements.[15,18,24]

Commonly, caliper measurements were considered the golden standard against other measurement techniques. Shellhart *et al.,*[25] used the vernier calipers and needlepoint dividers to calculate Bolton's values. They found that vernier calipers obtained higher reliability, compared to the needlepoint dividers. A digital vernier caliper was utilized in this study to eliminate the possibility of parallel error. In digital approaches, the anatomical mesial contact point to the distal contact point of each tooth parallel to the occlusal plane was considered the longest mesiodistal diameter. The mesiodistal width of the tooth and the digital caliper were applied in the plaster model.

The results of one systematic study that obtained the measurements by scanning plaster models were similar to those achieved by the manual measurements of the models, which supported the reliability of intra-arch dimension measurements by the digital approaches, compared to the plaster models.[9] In a study performed by Fleming *et al.,*[26] no differences were found between digital and plaster models in terms of dental measurements. However, in our study, differences were reported among the intraoral scanner, CBCT, and plaster models in terms of the maxillary arch length measurement and inter-arch dimensions.

Results of the Becker study showed that CBCT systems failed to reach the accuracy from optical digitizers, however within the limits of their study, accuracy appeared to be sufficient for digital planning and forensic purposes.[27] Robben *et al.,*[28] investigated the accuracy of five different CBCT devices digitizing a plaster cast.

Their results demonstrated that some CBCT devices are suitable for the digitization of plaster casts and show very good clinical accuracy. Vogtlin *et al.,*[29] compared the accuracy of master models based on two intra-oral digital scanners and silicone impressions. Their results showed that accuracy of the master models obtained on the basis of the digital scans is clinically sufficient to fabricate bridges with up to four units.

Al-Mashraqi *et al.,*[30] observed that the digitally scanned physical model (DSPM), Trios color scanner digital model, and direct 3D CBCT digital model appear to be adequate, reliable, and time-saving alternatives to the orthodontic physical plaster study cast (PPSC) when analyzed using a digital caliper.

In this regard, systematic studies showed controversial findings. The discrepancies among various studies in terms of inter-arch dimensions and tooth size can be due to differences in measurement methods and selection of the measurement point's position or observers' error. Since any method of space analysis as a diagnostic method should be easy and fast with minimal errors, further studies should be conducted in this regard. Moreover, future studies are recommended to be conducted due to the lack of sufficient information on the superiority of approaches with plaster models, compared to the digital approaches, and lack of data on accuracy and reliability of digital approaches.[31,32]

Digital models produced by intra-oral scanners and CBCT eliminate the need for impressions materials; However, more studies are required to show the validity and reliability of digital methods, compared to the gold standard method (dental plaster models).

Advantages and Limitations

This study made a comparison among intraoral scanner, CBCT, and plaster models in terms of inter-arch dimensions. The use of experienced and trained specialists to measure the inter-arch dimensions increased the credibility of our findings.

In addition, it is suggested that future studies assess the other variables affecting the accuracy, reduction of error, speed, ease of software use, and the interaction of these variables with each other. The cost of the intraoral scanner is high, but it is conceivable that it can be amortized during the time.

CONCLUSION

In conclusion, the present study showed that the results of measuring tooth size and intra-arch dimensions in digital images obtained from intraoral scanner and CBCT were in most cases lower than the results obtained in the plaster models, although these differences are not clinically noticeable and digital systems are acceptable for clinical use in terms of accuracy.

CONFLICT OF INTERESTS

There was no conflict of interest regarding the publication of the study

ETHICS APPROVAL

The protocol of present study was approved by the Research Ethics Committee of Mashhad University of Medical Sciences (Ethical code: IR.mums.sd.REC.1394.314) on 7 March 2018.

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AUTHORS' CONTRIBUTIONS

Hooman Shafaee: Conceptualization; Investigation; Methodology; Supervision; Data curation; Formal analysis; Funding acquisition; writing – original draft;

Fahimeh Farzanegan: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Supervision; writing – original draft; review and editing.

Bahareh Yaloodbardan: Data curation; Formal analysis; Investigation; Methodology; writing – original draft; review and editing.

SH Hoseini Zarch: Data curation; Formal analysis; Investigation;Methodology; writing – original draft; review and editing.

Abdolrasoul Rangrazi: Data curation; Formal analysis; Investigation; Methodology; writing – original draft; review and editing.

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REFERENCES.

1. Petrescu SM, Ţuculină MJ, Popa DL, Duţă A, Sălan AI, Voinea Georgescu R, Diaconu OA, Turcu AA, Mocanu H, Nicola AG, Dascălu IT. Modeling and Simulating an Orthodontic System Using Virtual Methods. *Diagnostics (Basel)*. 2022;12(5):1296. https://doi.org/10.3390/diagnostics12051296. PMID: 35626452; PMCID: PMC9141121.

2. Tepedino M, Cornelis MA, Chimenti C, Cattaneo PM. Correlation between tooth size-arch length discrepancy and interradicular distances measured on CBCT and panoramic radiograph: an evaluation for miniscrew insertion. *Dent Press J Orthodont.* 2018;23:39.e1-. e13. https://doi.org/10.1590/2177-6709.23.5.39.e1-13.onl

3. Kumar KA, Gupta S, Sandhu H. Determination of mesiodistal width of maxillary anterior teeth using inner canthal distance. *Medical J Armed Forces India.* 2015;71:S376-S81. https://doi.org/10.1016/j.mjafi.2014.08.002

4. Julyan J, Julyan J, De Lange J. Comparison of three different instruments for orthodontic study model analysis. *South African Dental J.* 2020;75(6):298-302. https://doi.org/10.17159/2519-0105/2020/v75no6a2

5. Kasparova M, Grafova L, Dvorak P, Dostalova T, Prochazka A, Eliasova H, Prusa J, Kakawand S. Possibility of reconstruction of dental plaster cast from 3D digital study models. *Biomed Eng Online.* 2013;12:49. https://doi.org/10.1186/1475-925X-12-49. PMID: 23721330; PMCID: PMC3686614.

6. Pachêco-Pereira C, De Luca Canto G, Major PW, Flores-Mir C. Variation of orthodontic treatment decision-making based on dental model type: A systematic review. *The Angle Orthodontist.* 2014;85(3):501-9. https://doi.org/10.2319/051214-343.1

7. Rebong RE, Stewart KT, Utreja A, Ghoneima AA. Accuracy of three-dimensional dental resin models created by fused deposition modeling, stereolithography, and Polyjet prototype technologies: A comparative study. *The Angle Orthodont.* 2018;88(3):363-9. https://doi.org/10.2319/071117-460.1

8. Cantín M, Muñoz M, Olate S. Generation of 3D tooth models based on three-dimensional scanning to study the morphology of permanent teeth. *Int J Morphol.* 2015;33(2):782-7. https://doi.org/10.4067/S0717-95022015000200057

9. De Luca Canto G, Pachêco-Pereira C, Lagravere M, Flores-Mir C, Major P. Intra-arch dimensional measurement validity of laser-scanned digital dental models compared with the original plaster models: a systematic review. *Orthod Craniofacial Res.* 2015;18(2):65-76. https://doi.org/10.1111/ocr.12068

10. Erten O, Yılmaz BN. Three-dimensional imaging in orthodontics. Turkish J Orthodont. 2018;31(3):86. https://doi.org/10.5152/TurkJOrthod.2018.17041

11. Christopoulou I, Kaklamanos EG, Makrygiannakis MA, Bitsanis I, Perlea P, Tsolakis AI. Intraoral Scanners in Orthodontics: A Critical Review. Inter J Environment Res Public Health. 2022;19(3):1407. https://doi.org/10.3390/ijerph19031407

12. Mangano F, Gandolfi A, Luongo G, Logozzo S. Intraoral scanners in dentistry: a review of the current literature. *BMC Oral Health.* 2017;17(1):1-11. https://doi.org/10.1186/s12903-017-0442-x

13. Grünheid T, McCarthy SD, Larson BE. Clinical use of a direct chairside oral scanner: an assessment of accuracy, time, and patient acceptance. *Am J Orthod Dentofacial Orthop.* 2014;146(5):673-82. https://doi.org/10.1016/j.ajodo.2014.07.023

14. Impellizzeri A, Horodynski M, De Stefano A, Palaia G, Polimeni A, Romeo U, Guercio-Monaco E, Galluccio G. CBCT and Intra-Oral Scanner: The Advantages of 3D Technologies in Orthodontic Treatment. *Int J Environ Res Public Health.* 2020;17(24):9428. https://doi.org/10.3390/ijerph17249428. PMID: 33339197; PMCID: PMC7765620.

15. Wiranto MG, Engelbrecht WP, Nolthenius HET, van der Meer WJ, Ren Y. Validity, reliability, and reproducibility of linear measurements on digital models obtained from intraoral and cone-beam computed tomography scans of alginate impressions. *Am J Orthod Dentofacial Orthop.* 2013;143(1):140-7. https://doi.org/10.1016/j.ajodo.2012.06.018

16. Farzanegan F, Zarch SHH, Mobasheri MF, Rangrazi A. Evaluation of the relationship between morphology, volume, and density of the mandible and dentofacial vertical dimension using cone beam computed tomography. *Pesqui Bras Odontopediatria Clin Integr.* 2020;19. https://doi.org/10.4034/PBOCI.2019.191.128

17. Alassiry AM. CLINICAL ASPECTS OF DIGITAL THREE-DIMENSIONAL INTRAORAL SCANNING IN ORTHODONTICS-A SYSTEMATIC REVIEW. *The Saudi Dent J.* 2023.

18. Stevens DR, Flores-Mir C, Nebbe B, Raboud DW, Heo G, Major PW. Validity, reliability, and reproducibility of plaster vs digital study models: comparison of peer assessment rating and Bolton analysis and their constituent measurements. *Am J Orthod Dentofacial Orthop.* 2006;129(6):794-803. https://doi.org/10.1016/j.ajodo.2004.08.023

19. Torassian G, Kau CH, English JD, Powers J, Bussa HI, Marie Salas-Lopez A, et al. Digital models vs plaster models using alginate and alginate substitute materials. *The Angle Orthodontist.* 2010;80(4):662-9. https://doi.org/10.2319/072409-413.1

20. Cuperus AMR, Harms MC, Rangel FA, Bronkhorst EM, Schols JG, Breuning KH. Dental models made with an intraoral scanner: a validation study. *Am J Orthod Dentofacial Orthop.* 2012;142(3):308-13. https://doi.org/10.1016/j.ajodo.2012.03.031

21. Cerroni S, Pasquantonio G, Condò R, Cerroni L. Orthodontic fixed appliance and periodontal status: An updated systematic review. Open Dent J 2018;12:614. https://doi.org/10.2174/1745017901814010614

22. Proffit WR, Fields Jr HW, Sarver DM. *Contemporary orthodontics*: Elsevier Health Sciences; 2006.

23. Kumar AA, Phillip A, Kumar S, Rawat A, Priya S, Kumaran V. Digital model as an alternative to plaster model in assessment of space analysis. J Pharm Bioallied Sci. 2015;7(Suppl 2):S465. https://doi.org/10.4103/0975-7406.163506

24. Leifert MF, Leifert MM, Efstratiadis SS, Cangialosi TJ. Comparison of space analysis evaluations with digital models and plaster dental casts. *Am J Orthod Dentofacial Orthop.* 2009;136(1):16. e1-e4. https://doi.org/10.1016/j.ajodo.2008.11.019

25. Shellhart WC, Lange DW, Kluemper GT, Hicks EP, Kaplan AL. Reliability of the Bolton tooth-size analysis when applied to crowded dentitions. *The Angle Orthodontist.* 1995;65(5):327-34.

26. Fleming P, Marinho V, Johal A. Orthodontic measurements on digital study models compared with plaster models: a systematic review. *Orthod Craniofacial Res.* 2011;14(1):1-16. https://doi.org/10.1111/j.1601-6343.2010.01503.x

27. Becker K, Schmücker U, Schwarz F, Drescher D. Accuracy and eligibility of CBCT to digitize dental plaster casts. Clinical Oral Investigations. 2018;22(4):1817-23. https://doi.org/10.1007/s00784-017-2277-x

28. Robbena J, Muallahb J, Wesemannc C, Nowakd R, Mahe J, Pospiechf P, et al. Suitability and accuracy of CBCT model scan: an in vitro study Eignung und Genauigkeit von DVT-Aufnahmen für die Digitalisierung von Gipsmodellen: Eine In-vitro-Untersuchung. *Int J Comput Dent.* 2017;20(4):363-75.

29. Vögtlin C, Schulz G, Jäger K, Müller B. Comparing the accuracy of master models based on digital intra-oral scanners with conventional plaster casts. *Physics in Medicine.* 2016;1:20-6. https://doi.org/10.1016/j.phmed.2016.04.002

30. Al-Mashraqi AA, Alhammadi MS, Gadi AA, Altharawi RA, Zamim KAH, Halboub E. Accuracy and reproducibility of permanent dentitions and dental arch measurements: comparing three different digital models with a plaster study cast. *Int J Comput Dent.* 2021;24(4):353-62.

31. Goracci C, Franchi L, Vichi A, Ferrari M. Accuracy, reliability, and efficiency of intraoral scanners for full-arch impressions: a systematic review of the clinical evidence. *European journal of orthodontics.* 2016;38(4):422-8. https://doi.org/10.1093/ejo/cjv077

32. Khraishi H, Duane B. Evidence for use of intraoral scanners under clinical conditions for obtaining full-arch digital impressions is insufficient. *Evidence-based dentistry.* 2017;18(1):24-5. https://doi.org/10.1038/sj.ebd.6401224