Clinical, Cosmetic and Investigational Dentistry

Dovepress
Taylor & Francis Group

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ORIGINAL RESEARCH

The Accuracy, Reproducibility, and Reliability of Orthodontic Measurements Obtained from Conventional Plaster Models versus Digital Orthodontic Models

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Background: Digital models are increasingly being proposed as an alternative to conventional plaster models in orthodontics. This study aims to evaluate the measurements obtained by CEREC Ortho software in terms of its accuracy, intraexaminer and interexaminer reliability, reproducibility, and time efficiency.

Methods: Twenty conventional plaster models were scanned into CEREC Ortho software by three independent examiners. Linear measurements in the transverse (y-axis), anteroposterior (x-axis), and vertical (z-axis) planes acquired by the software were compared with those obtained manually using an electronic digital caliper.

Results: Statistically significant differences were observed in the mean values of all measurements between the two methods; however, the majority of these differences were within clinically acceptable limits. Only a few measurements obtained by the software showed statistical difference upon assessing intraexaminer and interexaminer reliability. Manual measurements showed a higher correlation. The average software scanning time was 2.67 ± 1.30 min. The time required for obtaining measurements was significantly less for the electronic digital caliper.

Conclusion: Measurements obtained using CEREC Ortho software demonstrated acceptable accuracy and reliability under laboratory conditions and may be considered a reliable complementary tool to conventional plaster models in orthodontic diagnosis and treatment planning. This study is among the first to evaluate CEREC Ortho software in terms of accuracy, intraexaminer and interexaminer reliability, reproducibility, and time efficiency.

Keywords: digital, CEREC ortho, software, dental models

Introduction

Orthodontic treatment planning for any type of orthodontic treatment, whether conventional or lingual orthodontics, is a complex and lengthy process that requires a thorough and comprehensive analysis of different types of diagnostic records.[1,2] One of the essential diagnostic records in dentistry is dental models.[3,4] To date, conventional plaster dental models have been considered the reference method for occlusal assessment, diagnosis, and orthodontic treatment planning.[5,6] A conventional plaster dental model is a three-dimensional (3D) replica of a patient's dentition,[3,4] traditionally produced using an alginate impression, irreversible hydrocolloid, that is subsequently poured in a lab using orthodontic plaster (type II dental stone).[7]

https://doi.org/10.2147/CCIDE.S576536
Received: 24 October 2025
Accepted: 21 January 2026
Published: 12 February 2026

As modern dentistry is shifting towards electronic patient records and digital dentistry is flourishing, significant software and hardware developments have been taking place in dental scanning technology since its introduction in the mid-1990s.[8,9] Consequently, digital dental models produced through this technology are proposed as an alternative to conventional plaster dental models.[10–19] This trend is seen both clinically and academically.[8]

Utilizing digital dental models can eliminate many of the inherent problems associated with conventional plaster models. For example, with digital dental models, the usual concern about the durability and the risk of damage or breakage of conventional plaster dental models is non-existent.[14] Additionally, because digital dental models are stored as electronic data, the large physical space needed to accommodate a large collection of conventional plaster dental models is no longer required.[20] Furthermore, digital dental models offer several additional advantages over conventional plaster dental models. In contrast, some cons of using digital dental models are the possibility of permanent loss of electronic records, possible risks to privacy and security, and the high initial setup costs.[7–9]

Various studies depicted that digital dental models obtained from commercially available software are as valid as conventional plaster dental models in terms of accuracy of measurements, reproducibility, and reliability.[10–19] From a clinical perspective, even small measurement errors may influence orthodontic diagnosis and treatment planning, particularly in space analysis, arch width assessment, and vertical tooth positioning. Previous orthodontic studies have suggested that measurement discrepancies below approximately 0.5 mm are generally considered clinically acceptable, emphasizing the importance of distinguishing statistical significance from clinical relevance. Well-established digital orthodontic model systems, such as 3Shape and iTero, have been extensively evaluated and are widely used in clinical orthodontic practice, serving as reference platforms for the validation of digital model accuracy and reliability.[10–19] Nevertheless, to our knowledge, only one study has directly evaluated CEREC Ortho software (CEREC Ortho software, version 1.2.1, Dentsply Sirona, USA) in terms of accuracy and precision, with limited available data regarding examiner-related reliability and time efficiency, which are essential for routine clinical application.[21] Another study evaluated the precision of guided digital scanning procedures but did not directly assess orthodontic measurements obtained using CEREC Ortho software.[22] No other published studies written in the English language have investigated measurements obtained using CEREC Ortho software with respect to intraexaminer and interexaminer reliability, reproducibility, and time efficiency. As this system is relatively new to the market, an evaluation of its performance is warranted.

Despite the increasing adoption of digital orthodontic models, previous studies evaluating commercially available digital systems have reported certain limitations in measurement accuracy. These limitations have been attributed to factors such as difficulty in consistent point identification, variability among examiners, differences in accuracy across transverse, anteroposterior, and vertical planes, and dependence on software-specific measurement algorithms.[10–15] In addition, discrepancies between digital and conventional measurements have been reported, particularly for anteroposterior and vertical dimensions,[10–13] highlighting the need for further validation of newly introduced digital orthodontic software systems. Assessing linear measurements across transverse, anteroposterior, and vertical planes is clinically relevant, as orthodontic diagnosis and treatment planning rely on accurate three-dimensional evaluation of arch width, tooth position, and vertical relationships. Therefore, the aim of this study was to compare the orthodontic measurements obtained from a digital orthodontic software (CEREC Ortho software, 1.2.1, Dentsply Sirona, USA) and conventional plaster models using a digital caliper in regards of their accuracy, intraexaminer, and interexaminer reliability, reproducibility and time efficiency.

Materials and Methods

This experimental lab-based study was conducted at the dental laboratory of the College of Dentistry at King Saud bin Abdulaziz University for Health Sciences in Riyadh, Saudi Arabia. A typodont (D85SDP-200; Kilgore International Inc., Coldwater, MI, USA) was used to produce stone duplicates. The use of a standardized typodont ensured identical tooth morphology, arch form, and occlusal relationships across all samples. For this purpose, ten alginate impressions of each typodont arch were made (Dentsply GAC, Bohemia, Charlotte, NC, USA) and poured using Type II dental stone (orthodontic gypsum; Orthodontic Stone, Whip Mix Corp., Louisville, KY, USA) to produce a total of 20 conventional plaster dental models (ten maxillary and ten mandibular). The alginate: water ratio, plaster: water ratio, water temperature, and room temperature were standardized for all models following the manufacturers' recommendations. This was implemented to eliminate any risk of dimensional changes through the reproduction process.

The sample size was determined based on methodological precedent from previously published orthodontic reliability and agreement studies rather than a formal power calculation, as the primary aim was to assess measurement reliability and agreement. Similar sample sizes have been shown to be sufficient for evaluating intraexaminer and interexaminer reliability in comparable orthodontic measurement studies.

The models were scanned using CEREC Omnicam intraoral camera into CEREC Ortho software (CEREC Ortho software, 1.2.1, Dentsply Sirona, USA) by three independent examiners twice at two-time intervals with a minimum of 72 h to eliminate recall bias. Examiners were blinded to their previous measurements and to measurements obtained using the alternative method during repeated measurement sessions. The scanned digital dental models and the conventional plaster dental models were measured in different planes; transverse (*y*-axis), anterior posterior (*x*-axis), and vertical (*z*-axis). The manual measurements obtained from the conventional plaster dental models were measured using an electronic digital caliper (S225, Fowler, Boston, MA, USA). All measurements were recorded in millimeters (mm). Each set of measurements was timed and recorded in minutes and seconds.

Parameters Evaluated

In the context of this study, the term accuracy was used to describe the degree of agreement between measurements obtained from digital dental models and those obtained from conventional plaster models. While ISO 5725–1 distinguishes accuracy into trueness and precision, the present study focused on agreement between measurement methods rather than absolute deviation from a reference standard. Examiner-related variability was assessed using repeated measurements and multiple examiners and is therefore described using the terms intraexaminer and interexaminer reliability.

Repeatability and Reproducibility

The terms "repeatability", "reproducibility", and "reliability" are often used interchangeably with varying degree of consistency in the literature.[23,24] Repeatability is defined as "variation in the repeated measurements made on the same subject under identical conditions".[25] It is measured by denoting the difference between a pair of repeated measurements by the same examiner and the same method (ie, intraexaminer reliability).[24] Whereas reproducibility is defined as "variation in measurements made on a subject under changing conditions".[25] It is measured by comparing the measurements obtained by different examiners and determining the level of consistency (ie, interexaminer reliability).[24]

Accuracy

Accuracy is defined as "The degree to which a measurement or an estimate based on measurements represents the true value of the attribute that is being measured".[23] It is measured by comparing the measurements obtained by the two methods and by determining the level of agreement between the digital dental models and the conventional plaster dental models.

Time Efficiency

Efficiency is defined as "The effects or end results achieved in relation to the effort expended in terms of money, resources, and time".[23] Time efficiency was measured in minutes and seconds. The scanning time for each model was recorded to assess the time efficiency of the software. The time required for obtaining measurements in the first readings (R1) and the second readings (R2) were compared for both methods independently, and then subsequently compared between the two measuring methods: the electronic digital caliper and the CEREC Ortho software.

Dimensions Measured

Transverse

In the transverse plane, inter-canine, inter-molar, and inter-premolar distances were taken for each arch (Figure 1A–C).[26] Inter-canine width was measured from the cusp tip of the right canine to the collateral canine cusp tip. Inter-premolar measurements

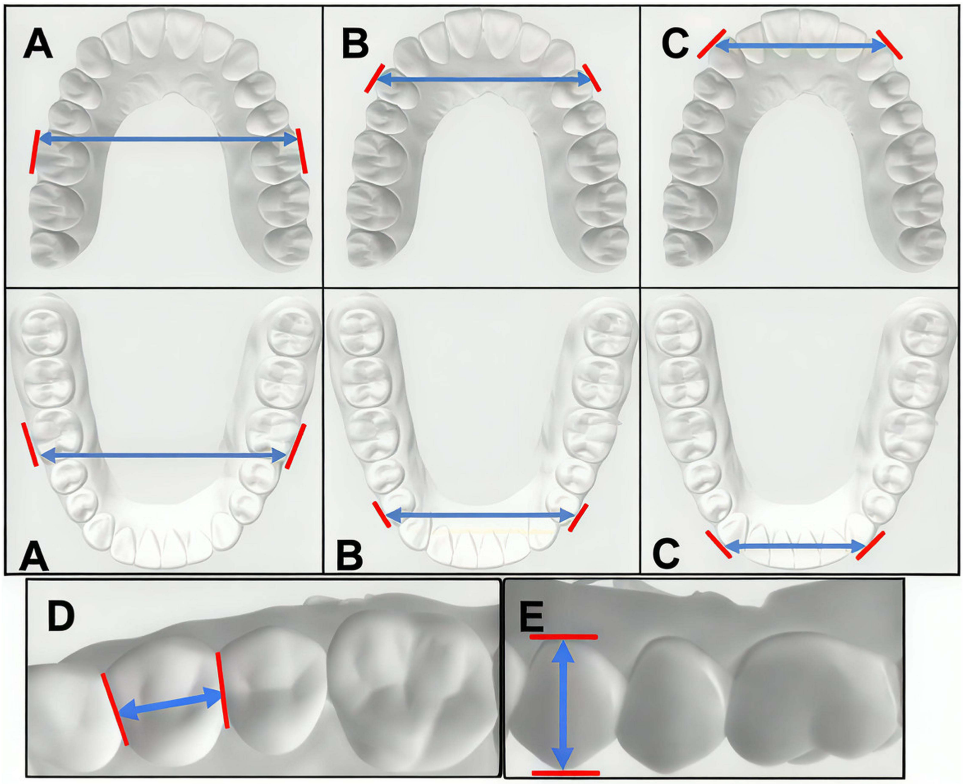

Figure 1 Linear arch measurements used in this study in the transverse plane (y-axis); (**A**) Inter-molar width, (**B**) Inter-premolar width, and (**C**) Inter-canine width. (**D**) Anterior-posterior plane (x-axis) (**E**) Vertical plane (z-axis).

were from the cusp tip of the buccal cusps of the 1st premolars from the right to the left side. Inter-molar measurements were from the cusp tip of the mesiobuccal cusp of the right first molar to the collateral mesiobuccal cusp of the other side.

Anterior-Posterior

The anteroposterior measurements were taken for the first molar, premolar, and canine on both right and left sides at the most mesiobuccal contact point to the most distobuccal contact point[17] (Figure 1D).

Vertical

For the vertical measurement, the first molar, premolar, and canine on both right and left sides were measured in the middle of its long axis on the buccal surface from the height of the crestal bone to the cusp tip[17] (Figure 1E).

Statistical Analysis

The data were entered and analyzed using Statistical Package for Social Sciences (SPSS 23 software, Chicago, IL, USA). Numerical data were presented as means and standard deviations (SD). Paired *t*-test was used to assess intraexaminer reliability, accuracy, and time efficiency. Analysis of variance (ANOVA) was used to compare measurements' means by the three independent examiners (ie, interexaminer reliability). Correlation coefficient and intraclass correlation were performed to determine the level of agreement between examiners, and it was interpreted according to Koo and Li (2016).[27] For comparison between the manual and digital methods, the mean values of the three examiners were averaged and used for subsequent analysis. The result was considered significant if p-value < 0.05. Correlation strength was interpreted as weak (<0.30), moderate (0.30–0.70), and strong (>0.70). Prior to inferential analysis, data normality was assessed using the Shapiro–Wilk test, and homogeneity of variances was evaluated using Levene's test. The assumptions for parametric testing were satisfied; therefore, paired t-tests and ANOVA were considered appropriate for the statistical comparisons performed.

Results

Intraexaminer reliability analysis demonstrated high consistency between repeated measurements for both methods, with only a limited number of measurements showing statistically significant differences between readings (Table 1). None of the measurements obtained by the electronic digital caliper demonstrated a significant difference between the first and second reading among the examiners except for the right premolar height (−0.09 ± 0.26, $p = 0.01$) and left molar height (0.10 ± 0.35, $p = 0.04$). While for the measurements obtained by CEREC Ortho software, right molar width (−0.16 ± 0.42, $p < 0.001$), left molar width (−0.13 ± 0.40, $p = 0.02$), and left molar height (0.10 ± 0.38, $p = 0.04$) showed significant difference. The Pearson correlation coefficient was significantly different from zero in all measurements obtained by the electronic digital caliper, which means that the two readings are correlated, whereas for the measurements obtained by the CEREC Ortho software, right and left molar heights and right and left canine heights were not correlated ($p > 0.05$).

The interexaminer reliability between the three examiners for the maxillary and mandibular dental models is presented in Tables 2 and 3, respectively. All the measurements obtained by the electronic digital caliper for both maxillary and mandibular dental models showed a significant difference, while only a few measurements were significant in terms of the CEREC Ortho software method. Most of the measurements obtained from CEREC Ortho software were larger than those obtained from the electronic digital caliper. The interclass correlation for assessing the interexaminer reliability for the measurements obtained by both methods is shown in Table 4. Only four measurements obtained by the electronic digital caliper showed poor correlation compared to seven measurements obtained by the CEREC Ortho software. Right and left premolar width, right molar height, and left canine height were poorly correlated in both measuring methods.

There was a significant difference in the means of all the measurements; transverse (y-axis), anterior posterior (x-axis), and vertical plane (z-axis) between the two methods ($p < 0.05$). The correlation coefficient revealed that the values of all the variables were fluctuating (highest [0.99] for the y-axis movement; inter-molar, inter-premolar, and inter-canine width, and lowest [−0.10] for the z-axis movement of the left canine) (Table 5).

The average scanning time for the digital dental model was 2.67 ± 1.30 min. There was no significant difference in scanning time between R1 and R2 (2.76 ± 0.99 vs 2.63 ± 1.62, $p = 0.54$). The mean time required for obtaining measurements by the electronic digital caliper was significantly less in R2 than in R1 (3.23 ± 0.59 vs 2.78 ± 0.59, $p < 0.001$). However, no

Table 1 Intraexaminer Reliability for the Measurements Obtained by the Electronic Digital Caliper and CEREC Ortho Software

Measurements	Electronic Digital Caliper				CEREC Ortho Software			
	Mean Differences (mm) ± SD (mm)	Paired *t*-Test	Pearson Correlation		Mean Differences (mm) ± SD (mm)	Paired *t*-Test	Pearson Correlation	
		p-value	r	*p*		*p*-value	r	*p*
Inter molar width	0.06 ± 0.068	0.52	0.979	<0.001	−0.02 ± 0.64	0.80	0.984	<0.001
Inter premolar width	0.10 ± 0.79	0.31	0.982	<0.001	−0.06 ± 0.51	0.35	0.993	<0.001
Inter canine width	−0.16 ± 0.64	0.06	0.992	<0.001	−0.02 ± 0.43	0.75	0.996	<0.001
Right molar width	−0.06 ± 0.32	0.13	0.841	<0.001	−0.16 ± 0.42	<0.001 *	0.612	<0.001
Right premolar width	0.05 ± 0.29	0.15	0.789	<0.001	−0.03 ± 0.41	0.60	0.351	0.01
Right canine width	−00.32 ± 0.02	0.69	0.809	<0.001	−0.07 ± 0.47	0.26	0.377	0.003
Left molar width	−00.32 ± 0.02	0.61	0.829	<0.001	−0.13 ± 0.40	0.02 *	0.64	<0.001
Left premolar width	−00.31 ± 0.01	0.73	0.74	<0.001	−0.01 ± 0.34	0.79	0.281	0.03
Left canine width	−00.36 ± 0.01	0.90	0.84	<0.001	−0.02 ± 0.32	0.69	0.644	<0.001
Right molar height	−00.39 ± 0.04	0.46	0.679	<0.001	−0.09 ± 0.45	0.13	0.123	0.35 **
Right premolar height	−00.26 ± 0.09	0.01 *	0.905	<0.001	−0.07 ± 0.43	0.19	0.592	<0.001
Right canine height	−00.20 ± 0.03	0.26	0.928	<0.001	−0.06 ± 0.57	0.43	0.188	0.15 **
Left molar height	00.35 ± 0.10	0.04 *	0.753	<0.001	0.10 ± 0.38	0.04 *	0.207	0.11 **
Left premolar height	00.30 ± 0.05	0.21	0.882	<0.001	−0.01 ± 0.47	0.83	0.415	0.001
Left canine height	00.22 ± 0.04	0.16	0.9	<0.001	0.07 ± 0.42	0.18	0.092	0.48 **

Notes: $^{*}p < 0.05$ indicates that there is a significant difference between the two readings. $^{**}p > 0.05$ indicates that the two readings are not correlated.

Table 2 Interexaminer Reliability for the Measurements Obtained by the Electronic Digital Caliper and CEREC Ortho Software for the Maxillary Dental Models

Measurements	Electronic Digital Caliper				CEREC Ortho Software			
	Operator 1	Operator 2	Operator 3	*p*-value *	Operator 1	Operator 2	Operator 3	*p*-value *
	Mean (mm) ± SD (mm)				Mean (mm) ± SD (mm)			
Inter molar width	53.4 ± 0.5	53.3 ± 0.5	52.3 ± 0.4	<0.001 *	53.9 ± 0.4	53.8 ± 0.3	53.6 ± 0.5	0.20
Inter premolar width	43.9 ± 0.6	43.5 ± 0.4	42.8 ± 0.8	<0.001 *	44.0 ± 0.4	43.9 ± 0.4	43.5 ± 0.2	<0.001 *
Inter canine width	36.5 ± 0.6	35.9 ± 0.4	34.8 ± 0.5	<0.001 *	36.1 ± 0.4	36.0 ± 0.3	35.8 ± 0.2	0.01 *
Right molar width	10.5 ± 0.2	10.4 ± 0.2	9.4 ± 0.3	<0.001 *	10.9 ± 0.4	10.7 ± 0.3	10.7 ± 0.4	0.43
Right premolar width	6.7 ± 0.1	6.5 ± 0.2	6.1 ± 0.2	<0.001 *	7.3 ± 0.4	7.0 ± 0.2	7.3 ± 0.3	0.01 *
Right canine width	7.6 ± 0.3	7.5 ± 0.2	6.9 ± 0.1	<0.001 *	7.8 ± 0.4	7.6 ± 0.2	7.8 ± 0.3	0.05
Left molar width	10.3 ± 0.2	10.1 ± 0.2	9.4 ± 0.5	<0.001 *	10.7 ± 0.5	10.6 ± 0.3	10.6 ± 0.4	0.44
Left premolar width	6.7 ± 0.1	6.6 ± 0.3	6.0 ± 0.2	<0.001 *	7.1 ± 0.4	7.0 ± 0.3	7.1 ± 0.2	0.49
Left canine width	7.8 ± 0.3	7.7 ± 0.2	6.9 ± 0.3	<0.001 *	7.7 ± 0.3	7.7 ± 0.2	7.9 ± 0.3	0.04 *
Right molar height	7.7 ± 0.3	8.1 ± 0.3	7.1 ± 0.4	<0.001 *	8.2 ± 0.2	7.9 ± 0.4	8.0 ± 0.3	0.01 *
Right premolar height	8.5 ± 0.2	8.5 ± 0.1	7.5 ± 0.3	<0.001 *	8.8 ± 0.3	8.5 ± 0.4	8.7 ± 0.3	0.05
Right canine height	10.6 ± 0.2	10.5 ± 0.1	9.5 ± 0.1	<0.001 *	10.7 ± 0.4	10.7 ± 0.4	10.8 ± 0.3	0.82
Left molar height	8.0 ± 0.3	7.6 ± 0.1	7.1 ± 0.3	<0.001 *	8.3 ± 0.3	8.0 ± 0.3	8.2 ± 0.3	0.01 *
Left premolar height	8.4 ± 0.4	8.2 ± 0.2	7.5 ± 0.2	<0.001 *	8.3 ± 0.4	8.2 ± 0.4	8.5 ± 0.3	0.05
Left canine height	10.3 ± 0.2	10.2 ± 0.1	9.4 ± 0.2	<0.001 *	10.4 ± 0.3	10.2 ± 0.5	10.5 ± 0.3	0.07

Note: *$p < 0.05$ indicates that there is a significant difference between the operators.

Table 3 Interexaminer Reliability for the Measurements Obtained by the Electronic Digital Caliper and CEREC Ortho Software for the Mandibular Dental Models

Measurements	Electronic Digital Caliper				CEREC Ortho Software			
	Operator 1	Operator 2	Operator 3	*p*-value *	Operator 1	Operator 2	Operator 3	*p*-value *
	Mean(mm) ± SD (mm)				Mean(mm) ± SD (mm)			
Inter molar width	47.0 ± 0.6	46.6 ± 0.7	46.1 ± 0.5	<0.001 *	47.0 ± 0.8	46.6 ± 0.4	46.8 ± 0.6	0.26
Inter premolar width	35.9 ± 0.6	35.7 ± 0.4	34.6 ± 0.4	<0.001 *	35.6 ± 0.4	35.7 ± 0.3	35.5 ± 0.5	0.41
Inter canine width	26.5 ± 0.5	25.9 ± 0.4	25.4 ± 0.6	<0.001 *	26.4 ± 0.5	26.3 ± 0.2	26.6 ± 0.4	0.09
Right molar width	10.9 ± 0.2	10.9 ± 0.2	10.6 ± 0.1	<0.001 *	11.2 ± 0.3	11.1 ± 0.2	11.7 ± 0.4	<0.001 *
Right premolar width	6.6 ± 0.2	6.5 ± 0.2	5.5 ± 0.2	<0.001 *	6.9 ± 0.3	6.8 ± 0.2	6.8 ± 0.3	0.39
Right canine width	6.9 ± 0.2	7.0 ± 0.1	6.3 ± 0.3	<0.001 *	7.2 ± 0.4	7.1 ± 0.2	7.3 ± 0.3	0.32
Left molar width	10.6 ± 0.3	10.8 ± 0.2	10.5 ± 0.2	<0.001 *	11.3 ± 0.3	11.0 ± 0.1	11.5 ± 0.3	<0.001 *
Left premolar width	6.4 ± 0.2	6.5 ± 0.2	5.7 ± 0.3	<0.001 *	6.9 ± 0.3	6.8 ± 0.2	7.0 ± 0.2	0.12
Left canine width	6.8 ± 0.2	7.1 ± 0.2	6.1 ± 0.2	<0.001 *	7.2 ± 0.2	7.2 ± 0.2	7.3 ± 0.3	0.19
Right molar height	8.0 ± 0.2	8.1 ± 0.2	7.3 ± 0.2	<0.001 *	8.3 ± 0.4	8.2 ± 0.2	8.4 ± 0.3	0.25
Right premolar height	7.9 ± 0.0	7.8 ± 0.1	7.0 ± 0.1	<0.001 *	7.9 ± 0.3	8.0 ± 0.2	8.0 ± 0.3	0.40
Right canine height	10.1 ± 0.1	10.1 ± 0.2	9.2 ± 0.2	<0.001 *	10.1 ± 0.5	10.2 ± 0.2	10.3 ± 0.3	0.18
Left molar height	8.3 ± 0.2	8.3 ± 0.2	7.7 ± 0.2	<0.001 *	8.4 ± 0.3	8.2 ± 0.3	8.1 ± 0.3	0.02 *
Left premolar height	7.6 ± 0.0	7.5 ± 0.1	6.6 ± 0.1	<0.001 *	7.8 ± 0.2	7.7 ± 0.2	7.8 ± 0.2	0.19
Left canine height	10.5 ± 0.1	10.3 ± 0.1	9.4 ± 0.1	<0.001 *	10.4 ± 0.4	10.5 ± 0.2	10.4 ± 0.2	0.29

Note: *$p < 0.05$ indicates that there is a significant difference between the operators.

significant time difference was depicted upon using the CEREC Ortho software in the two readings (4.38 ± 1.38 vs 4.13 ± 1.51, $p = 0.32$). Both R1 and R2 were less when comparing the electronic digital caliper measurements time to the CEREC Ortho software measurement time (R1 = 3.23 ± 0.59 vs 4.38 ± 1.38, $p < 0.001$, R2 = 2.78 ± 0.42 vs 4.13 ± 1.51, $p < 0.001$).(Table 6).

Table 4 The Interclass Correlation for Assessing the Interexaminer Reliability for the Measurements Obtained by the Electronic Digital Caliper and CEREC Ortho Software

Measurements	Electronic Digital Caliper			CEREC Ortho Software		
	Intraclass Correlation	95% Confidence Interval		Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound		Lower Bound	Upper Bound
Inter molar width	0.99	0.97	0.99	0.99	0.97	0.994
Inter premolar width	0.99	0.98	1.00	1.00	0.99	1.00
Inter canine width	0.99	0.99	1.00	1.00	0.99	1.00
Right molar width	0.61	0.36	0.80	0.44 *	0.16	0.7
Right premolar width	0.31 *	0.03	0.60	0.46 *	0.19	0.71
Right canine width	0.78	0.60	0.90	0.64	0.41	0.82
Left molar width	0.57	0.31	0.78	0.64	0.40	0.82
Left premolar width	0.17 *	−0.09	0.48	0.21 *	−0.05	0.52
Left canine width	0.86	0.73	0.94	0.68	0.46	0.85
Right molar height	0.20 *	−0.06	0.51	0.27 *	0.003	0.57
Right premolar height	0.91	0.82	0.96	0.73	0.53	0.87
Right canine height	0.83	0.69	0.92	0.48 *	0.21	0.72
Left molar height	0.73	0.53	0.87	0.14 *	−0.11	0.46
Left premolar height	0.82	0.66	0.92	0.60	0.34	0.79
Left canine height	0.17 *	−0.09	0.48	−0.08 *	−0.27	0.21

Note: *Poor correlation.

Table 5 Mean Differences of Transverse (*y*-Axis) Anterior Posterior (*x*-Axis), and Vertical Plane (*z*-Axis) Between the Digital Dental Models and the Conventional Plaster Dental Models

Measurements	Mean Differences	Paired *t*-Test		Pearson Correlation	
		t	*p*-value	r	*p*
Transverse (*y*-axis)					
Inter molar width	−0.52 ± 0.62	−6.55	<0.001 *	0.99	<0.001
Inter premolar width	−0.28 ± 0.59	−3.75	<0.001 *	0.99	<0.001
Inter canine width	−0.38 ± 0.69	−4.27	<0.001 *	0.99	<0.001
Anteroposterior (*x*-axis)					
Right molar width	−0.62 ± 0.51	−9.36	<0.001 *	0.45	<0.001
Right premolar width	−0.69 ± 0.44	−12.22	<0.001 *	0.27	0.04
Right canine width	−0.43 ± 0.41	−8.07	<0.001 *	0.51	<0.001
Left molar width	−0.66 ± 0.41	−12.41	<0.001 *	0.61	<0.001
Left premolar width	−0.67 ± 0.47	−10.90	<0.001 *	−0.08	0.52 **
Left canine width	−0.46 ± 0.55	−6.51	<0.001 *	0.44	<0.001
Vertical (*z*-axis)					
Right molar height	−0.46 ± 0.52	−6.93	<0.001 *	−0.08	0.53 **
Right premolar height	−0.45 ± 0.55	−6.33	<0.001 *	0.39	0.00
Right canine height	−0.48 ± 0.58	−6.44	<0.001 *	0.12	0.37 **
Left molar height	−0.33 ± 0.43	−5.83	<0.001 *	0.32	0.01
Left premolar height	−0.43 ± 0.58	−5.79	<0.001 *	0.32	0.01
Left canine height	−0.38 ± 0.52	−5.70	<0.001 *	−0.10	0.44 **

Notes: *$p < 0.05$ indicates that there is a significant difference between the two methods. **$p > 0.05$ indicates that the two methods are not correlated.

Table 6 Time Efficiency Comparison Between Electronic Digital Caliper and CEREC Ortho Software

Methods	Measurement	Reading 1 (Mean ± SD, min)	Reading 2 (Mean ± SD, min)	p-value
CEREC Ortho	Scanning time	2.76 ± 0.99	2.63 ± 1.62	0.54
Electronic digital caliper	Measurement time	3.23 ± 0.59	2.78 ± 0.42	<0.001*
CEREC Ortho	Measurement time	4.38 ± 1.38	4.13 ± 1.51	0.32

Note: *Significant at p < 0.05.

Discussion

CEREC Ortho software (CEREC Ortho software, 1.2.1, Dentsply Sirona, USA) is a new software in the market that has been reported twice in the literature in terms of its accuracy and precision. Şakar et al have assessed the accuracy of CEREC Ortho software by comparing its measurements with the manual method, while Zimmermann et al have tested the software's precision in vivo by comparing the exported stereolithography files (STL).[21,22] However, to our knowledge, CEREC Ortho software's intraexaminer and interexaminer reliability and time efficiency have not been tested in the literature. The aim of the current study was to evaluate measurements obtained by this system in terms of its accuracy, reliability, reproducibility, as well as its time efficiency. CEREC Ortho software showed acceptable accuracy and reliability under controlled laboratory conditions. The average scanning time for the digital dental model was 2.67 ± 1.30 min. The time required to obtain the measurements was significantly less when comparing the electronic digital caliper with CEREC Ortho software.

There was a significant difference in the overall mean difference in the measurements between the two methods (Table 5). However, the majority (67%) of the mean differences were deemed clinically acceptable (i.e., <0.5 mm), according to Asquith and McIntyre guidelines.[28–30] This agrees with other studies that considered the clinical significance and analysis of measurement error.[24,31] The correlation coefficient values presented in Table 5 fluctuated, indicating that the level of agreement between the two methods is relatively limited. Although correlation measures do not fully characterize agreement between measurement methods, they remain widely used in orthodontic reliability research and were complemented in the present study by intraclass correlation coefficients and interpretation of clinically acceptable error thresholds. This finding agrees with other studies where a statistical difference has been depicted upon comparing digital dental models with conventional plaster dental models.[10–12,21] Reuschl et al reported a statistical difference in the overall comparison between the two methods; nevertheless, since most of the measurements were <0.05 mm, the software was recommended for usage to replace conventional plaster dental models.[11] Koretsi et al reported substantial conformity (66.7%), concluding a limited agreement between the two methods.[10] Şakar et al reported that 50% of the compared results showed statistical difference upon comparing the digital dental models obtained by Cerec Ortho software and the conventional plaster dental models; however, these differences were considered clinically acceptable.[21] Naidu and Freer and Wiranto et al depicted a statistical difference between the two methods for approximately one-third and one-fifth of teeth width measurements, respectively; however, both softwares were concluded to have a clinically acceptable accuracy.[12,13] Such variation in reporting previous studies' results might be attributed to the fact that there is no universal standard for acceptable errors or what is clinically insignificant in orthodontics. Different value thresholds were considered clinically acceptable throughout the literature ranging from 0.20 mm–0.05 mm.[24,30–34]

When compared with other digital orthodontic model systems reported in the literature, the performance of CEREC Ortho software appears comparable in terms of measurement accuracy and reliability. Previous studies evaluating digital orthodontic models have reported statistically significant differences when compared with conventional plaster models; however, these differences were generally within clinically acceptable thresholds.[10–15] Similar to earlier findings, transverse measurements demonstrated higher agreement than anteroposterior and vertical dimensions.[10–13] These observations suggest that CEREC Ortho software performs in line with existing digital systems while offering acceptable clinical reliability.

All the mean differences depicted in the intraexaminer reliability assessment (Table 1) for both methods were minute, and the ranges were clinically acceptable (ie, < 0.5 mm).[24,31] This is consonant with Koretsi et al findings of substantial intraexaminer reliability within each method.[10] Nalcaci et al and Akyalcin et al reported intraexaminer reliability very close to the ideal value of one for both methods, which is higher than the current study.[18,19] On the contrary, Reuschl et al reported a significant effect of the examiners in the manual method but not in the digital method.[11] This could be attributed to the variability in reliability measurements and data interpretation. The current paper, however, utilized the guidelines for reporting reliability and agreement.[35] The latest modification for the intraclass correlation coefficient values, proposed by Koo and Li (2016), was adopted in the current study; nevertheless, multiple studies had adopted the one proposed by Roberts and Richmond (1997).[27,36]

With regards to interexaminer reliability (Tables 2 and 3) and in contrast to the electronic digital caliper method, all the differences depicted using CEREC Ortho software were clinically insignificant (i.e., <0.5 mm).[24,31] Manual measurements obtained by electronic digital caliper showed a higher correlation (Tables 1 and 4). Our findings are consistent with Reuschl et al, where a statistical difference in the interexaminer variation was found; however, the software was concluded to be reliable. Moreover, manual measurements were found to have better reliability than digital ones; nevertheless, they were both considered clinically acceptable and reliable.[11] On the contrary, Koretsi et al reported higher reliability for the measurements obtained by the software than the manual method.[10] Naidu and Freer showed excellent intraexaminer and interexaminer reliability and a higher correlation for the software.[12] Intraexaminer reliability is usually greater than interexaminer reliability[24,31] This is mostly due to the number of examiners. In the current study, the number of independent examiners is three; however, if the number of examiners was reduced to only two, a significant difference would be harder to detect.[24]

Several factors influence measurement error; examiners' experience, learning curve, examiners' bias, point identifications and positioning, and type of the measurements conducted.[24,37] Although the examiners were trained before conducting the present study, repeated measurements still can vary although they are carried out by the same examiner.[38] An observed learning curve has been reported in the literature, and it can influence such results.[39] This can explain the significant reduction in the time required for the manual measurements between the first and second readings in the current study (3.23 ± 0.59 vs 2.78 ± 0.59, $p < 0.001$). However, the present study design does not allow assessment of long-term learning effects or changes in measurement performance over extended periods, which should be explored in future longitudinal investigations.

Point identification and positioning might be the greatest reason for errors in measurements.[31,40] A clear, unified point definition results in precise point identification among the examiners. Nevertheless, point positioning greatly relies on the properties of the measuring tools (ie, electronic digital caliper vs CEREC Ortho software) and the measured items (ie, conventional plaster dental models vs digital dental models).[10,41] In the present study, common definitions of anatomical points were adopted. However, a certain inaccuracy in point identification is almost always evident, which is characteristic of the model itself regardless of its type or the measurement method used. For instance, the anteroposterior measurements were taken from the most mesiobuccal contact point to the most distobuccal contact point; however, a contact point might rather be a contact area, especially in posterior teeth, resulting in variation of point identification among the examiners.[41] This could be observed in our results since the anterior-posterior (x-axis) and vertical (z-axis) measurements, in general, presented a lower correlation. It can be noted that the transverse plane (y-axis) measurements showed excellent correlation and a higher level of agreement in accuracy, reliability, and the reproducibility of both methods. This could be due to the precision of point identification in the transverse plane. It has been found that points allocated at the edges of the anatomical structures (i.e., buccal cusp tips of molars, premolars, and canines) are more accurately identifiable.[41] Another reason could be attributed to the greater numerical values of the transverse plane (y-axis) measurements than the rest, so the SD will not significantly affect the correlation. With respect to point positioning, the measuring tool properties might influence its accuracy.[10,41] Electronic digital calipers may not be able to access the maximum mesiodistal width of teeth, especially in crowding cases.[42] To reduce such measurement errors in the present study, a typodont (D85SDP-200; Kilgore International Inc., Coldwater, MI, USA) was used to produce stone duplicates. Digital software attempted to overcome such issues by imprinting certain features such as zooming and rotating the digital dental model, which facilitate precise point positioning.[14,15] This could explain why most of the current results were larger when measured by CEREC Ortho software than by the electronic digital caliper, which agrees with previously conducted studies.[10,14–16]

Lastly, the type of measurements could contribute to the factors influencing measurement errors. Computed measurements, such as the sum of upper and lowers incisors width, or those derived mathematically, such as Bolton, might be imprecise due to cumulative errors.[10] To overcome this, only linear measurements in all planes (i.e., transverse (y-axis), anterior posterior (x-axis), and vertical (z-axis) were carried out in the present study.

 https://doi.org/10.2147/CCIDE.S576536

The average CEREC Ortho software scanning time (2.67 ± 1.30 mm) was significantly lower when compared with the conventional plaster dental model and with other software.[10,13,43–46] Hiraguchi et al reported that the alginate impression takes approximately 7 min of chairside time per arch. However, the total working time, once laboratory procedures are considered, to obtain a conventional plaster dental model is 76 min, while Sfondrini et al and Grüheid et al reported the total time to be 22 min.[43–45] The reported scanning time of other software in the literature ranges from 3 to 23 min, depending on the software version used.[10,13,45,46] The time required for obtaining the measurements was significantly less when comparing the electronic digital caliper to CEREC Ortho software (R1 = 3.23 ± 0.59 vs 4.38 ± 1.38, $p < 0.001$, R2 = 2.78 ± 0.42 vs 4.13 ± 1.51, $p < 0.001$). Contrarily, ivoris®analyze 3D software was similar in time required to obtain the measurement in comparison to the manual method (8.36 ± 2.10 vs 7.59 ± 1.36).[8] Such variation in the scanning and measurement time is most likely due to methodological inconsistency; the differences in laboratory handling, some studies considered both arches as one sample, and certain studies were conducted among patients who most likely require more time as moisture control is essential.[47]

One of the limitations of the current study is that it was conducted on conventional plaster models rather than patient-derived digital scans. While the aim of the study was to compare conventional and digital dental models using a unified and standardized starting point, this in vitro approach may limit the direct generalizability of the findings to clinical conditions. In vivo factors such as saliva, patient movement, intraoral accessibility, and scanning technique may influence measurement accuracy and reproducibility. Another limitation relates to the type of measurements included. However, linear measurements have been shown to be more precise, and the present study focused on these measurements to evaluate the performance of the software while minimizing the effect of cumulative errors.[10] In addition, no formal a priori power calculation was performed, and therefore the findings were interpreted with emphasis on clinical relevance rather than statistical significance alone. Additionally, future research should compare CEREC Ortho software with other commercially available digital orthodontic systems and evaluate its performance using patient-derived scans, which would provide further clinically relevant insights. Although direct comparisons with other established digital systems such as 3Shape or iTero were beyond the scope of the present study, the findings provide essential baseline data regarding the reliability, reproducibility, and efficiency of CEREC Ortho software, which is a prerequisite for meaningful comparative investigations.

Conclusions

Digital dental models obtained using CEREC Ortho software demonstrated acceptable accuracy and reliability under controlled laboratory conditions, despite statistically significant differences when compared with conventional plaster models. Importantly, the majority of these differences were within clinically acceptable limits. Manual measurements obtained using electronic digital calipers showed slightly higher correlation values. Regarding time efficiency, the average scanning time for a digital model was 2.67 ± 1.30 min, and the time required to obtain measurements was significantly shorter using the electronic digital caliper than using CEREC Ortho software. The findings of the present study should be interpreted as software-specific validation data derived from an in vitro setting. Methodological limitations, including the use of typodont-based plaster models and the absence of in vivo conditions, restrict direct clinical extrapolation. Accordingly, further patient-based clinical studies are required to establish standardized guidelines for clinically acceptable measurement error, examiner reliability, and the integration of digital dental models into routine orthodontic practice.

Acknowledgments

Authors appreciate the opportunity given by King Abdullah International Medical Research Center and National Guard Health Affairs, Riyadh, Kingdom of Saudi Arabia, to conduct this research.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

This work was supported by King Abdullah International Medical Research Center and Health Affairs at the Ministry of the National Guard, Riyadh, Kingdom of Saudi Arabia [RC17/087/R].

Disclosure

The authors declare no conflicts of interest in this work.

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