THREE-DIMENSIONAL DIGITAL MODELS ACCURACY AND RELIABILITY: EXCEED™ SOFTWARE VALIDATION

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ABSTRACT

Introduction: CAD/CAM systems help orthodontists in the manufacture of aesthetic aligners and indirect bonding (virtual bracket positioning) in three-dimensional digital models. This study assessed the accuracy and validity of eXceed™ software. Methods: Twenty plaster models of patients were digitized using a table scanner and the obtained files were converted into stereolithography by the OrthoAnalyser™ software. Using the plaster and digital models, six measurements were performed: Intertermolar Width (IMW), Intercanine Width (ICW), Posterior Arch Length (AL), Premolar Crown Diameter (PD), Canine Crown Height (CH) and Overjet (OJ). Intraobserver systematic errors between the replicas were described as differences in absolute means and standard deviations (SD), they were statistically compared with the Student's t-test for paired data. The differences between the methods were evaluated using the Student's t-test. The random errors were quantified using the Method Error () and the Intraclass Correlation Coefficient (ICC). Results: Two of the measurements of the replicas in digital models (AL) and plaster models (ICW) showed statistically significant systematic errors. The ICC ranged from 0.916 to 0.997. The Method Errors were all less than 0.41mm (0.22mm). Bland-Altman graphs showed that the differences in repeatability between the two methods were within the limits of agreement. The values DP (0.253mm), ICW (0.396mm), CH (0.314mm) and AL (0.359mm) were higher in plaster models than in digital models. Conclusion: The measurements performed in both methods were reliable and reproducible, and the measurements of the plaster models were slightly higher than those of the corresponding digital models.

Descriptors: Orthodontics, computer-aided design, dental models, dimensional measurement accuracy, dental technology.

RESUMO

Introdução: Os sistemas CAD/CAM auxiliam ortodontistas na confecção de alinhadores estéticos e na colagem indireta (posicionamento virtual de bráquetes) em modelos digitais tridimensionais. Este estudo avaliou a precisão e validade do software eXceed™. Métodos: Vinte modelos de gesso de pacientes foram digitalizados utilizando um escâner de mesa e os arquivos obtidos foram convertidos em estereolitografia pelo software OrthoAnalyser™. Utilizando os modelos de gesso e digital, seis medidas foram aferidas: Largura Intermolares (LM), Largura Intercaninos (LC), Comprimento do Arco posterior (CA), Diâmetro da Coroa do Pré-Molar (DP), Altura da Coroa do Canino (AC) e Overjet (OJ). Os erros sistemáticos intraobservador entre as réplicas foram descritos como diferenças das médias absolutas e desvios-padrões (DP), foram comparados estatisticamente com o teste t de Student para dados pareados. As diferenças entre os métodos foram avaliadas usando o teste t de Student. Os erros aleatórios foram quantificados usando o erro do método [√Σ(d2/2N)] e o Coeficiente de Correlação Intraclasse (ICC). Resultados: Duas das medidas das réplicas em modelos digitais (CA) e de gesso (LC) demostraram erros sistemáticos estatisticamente significativos. O ICC variou de 0,916 a 0,997. Os erros do método foram todos inferiores a 0,41 mm (0,22 mm). Os gráficos de Bland-Altman mostraram que as diferenças de repetitividade entre os dois métodos estavam dentro dos limites de concordância. Os valores DP (0,253 mm), LC (0,396 mm), AC (0,314 mm) e CA (0,359 mm) foram maiores em modelos de gesso do que nos modelos digitais. Conclusão: As medidas realizadas em ambos os métodos foram confiáveis e reprodutíveis, e as medidas dos modelos de gesso foram ligeiramente maiores do que os dos modelos digitais correspondentes.

Descritores: Ortodontia, projeto auxiliado por computador, modelos dentários, precisão da medição dimensional, tecnologia odontológica.

INTRODUCTION

Traditionally, orthodontists perform diagnosis and treatment plan with the aid of clinical, radiographic examinations and plaster model[1]. The analysis of plaster models allows the clinician to view the occlusion from different perspectives that are not possible by clinical examination. In addition, linear distance measurements are easier to perform in physical models than in vivo[2]. Plaster models have important limitations and may suffer physical and chemical damage resulting in wear, especially when measured repeatedly. In addition, they are susceptible to distortions in volume over time due to weather conditions [3,4].

In order to address these issues, including additional storage-related costs, three-dimensional digital (3D) models were introduced in the late 1990s by OrthoCAD™[5]. So, digital models can be stored and accessed electronically from anywhere, facilitating sharing and communication between professionals[5,6]. In addition, they can be used by an orthodontic software, allowing measurements, assisting in the diagnosis, generating orthodontic setup[1,5,7], assisting in the production of aesthetic aligners and in brackets positioning and in the bonding procedure that is still a critical procedure for both the orthodontist and the patientperimeter, overjet, and overbite[8].

Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) systems applied to Orthodontics have allowed to improve the inaccuracy of accessory positioning during brackets bonding procedure[8]. Stereolithography (STL) files generated from intra or extraoral dental scanning on models of dental arches decreased or eliminated possible inaccuracies, enabling the use of these in computers, including mobile devices. Currently, some softwares available in the market have enabled orthodontists to position the brackets digitally with greater efficiency on the teeth of 3D models[8]. However, there are many doubts related to the reliability and accuracy of these softwares[6,8], leaving the clinician insecure in relation to the use of these systems.

Currently, orthodontic softwares are increasingly automated systems, simplifying the method and steps of planning and manufacturing orthodontic indirect bonding devices. Previous studies have demonstrated the accuracy and reliability of orthodontic software[5,6,8-13]. Some studies have demonstrated the accuracy and reliability of 3D virtual models when compared to the respective plaster models[10,13], while other studies showed less consistent results between the two methods[10,14-17]Copenhagen, Denmark. The purpose of the eXceed™ system is to turn the orthodontic office more efficient, aiding in orthodontic planning, simplifying processes, and assisting clinicians and laboratories in the manufacture of accurate devices for applications in the indirect bonding procedure (such as positioning and personalization of brackets virtually) and aesthetic aligners.

The eXceed™ system allows orthodontic setup and the choice and positioning of orthodontic brackets, in order to obtain the best results in the shortest possible time, minimizing the need for accessories repositioning and finishing folds in orthodontic arches. However, there are no previous studies that support the use of this system in the daily clinical practice. The aim of this study was to assess the accuracy and precision (reproducibility) of the eXceed™ measurement and diagnostic tools and compare with measurements obtained from the corresponding plaster models.

MATERIAL AND METHODS

Twenty patients aged between 15 and 38 years (eight male and twelve female patients) were selected and treated at the Dentistry University, Araraquara, /Unesp. The inclusion criteria of the cases were Angle Class I malocclusion, crowding or mild to moderate spacing (≤ 5mm), absence of transverse discrepancy and open bite, complete permanent dentition (excluding the 3rd molars). Exclusion criteria were dental anomalies in size and shape, severe gingival recession, erosions and abrasions in the dental crown that could influence the measurements. The research project was approved by the institutional Ethics Committee (# 2.451.252) and the Informed Consent Form was signed by all patients.

Plaster Models versus Digital Models

The models were obtained by molding the patients' dental arches with alginate Jeltrate® Plus (Dentsply, Rio de Janeiro, RJ, Brazil). The bite recording at the usual maximum intercuspidation was obtained with a dental wax blade no. 7 (Clássico, São Paulo, Brazil) and, later, it was used to cut the plaster models. The dental molds obtained were leaked within 1 hour after molding, with Type III plaster (Asfer, São Caetano do Sul, SP, Brazil). After 24 hours, the blisters and defects in the plaster were removed using a Lecron sculpting instrument (SSWhite Duflex, Juiz de Fora, MG, Brazil). After this stage, the plaster models were cut following standards and the instructions of the American Board of Orthodontics.

Scanning of all plaster models was performed by a 3Shape R700 table scanner (3Shape Ltda, Copenhagen, Denmark). Each of them was individually scanted to record the details of the dental arches and then occluded to record occlusion. The scanning time was 2.5 minutes per arch with scanning accuracy of 20 µm. The obtained images were automatically processed by the software Scanlt version 4.0.1 (3Shape Ltda, Copenhagen, Denmark) which generated a file with a 3sz extension. The files were then imported by the 3Shape OrthoAnalyzer™ software (3Shape Ltda, Copenhagen, Denmark) and converted to stereolithography (STL) files.

Measurements

The STL files were imported by the system software and six different measurements (Figure 1) were performed using the eXceed Pro Software tools (Roosikrantsi, Tallinn, Estonia). The first premolar crown diameter (PD) was measured between the mesial and distal contact points of the tooth on the left side. The Intercanine Width (ICW) was measured between the tips of the incisals of the right and left canines. The Intermolar Width (IMW) was measured between the tips of the mesiolingual cusps of the second molars. The Canine Crown Height (CH) was obtained from the tip of the incisal to the gingival level on the vestibular side of the right canine. The Posterior Arch Length (AL) was measured from the mesial of the first premolar to the distal of the second molar on the left side. Overjet (OJ) was measured from the vestibular surface at the level of the incisal edge of the left lower incisor more vestibularized to the palatine of the upper central incisor. Each measurement was performed twice, with an interval of one week between the first and second measurements by the same examiner (FCM), so that the accuracy and precision of each of the six protocols could be estimated. The same measurement protocol was performed in the plaster models, using a digital caliper with accuracy of 0.01mm (Digimess Instrumentos de Precisão Ltda., São Paulo, Brazil).

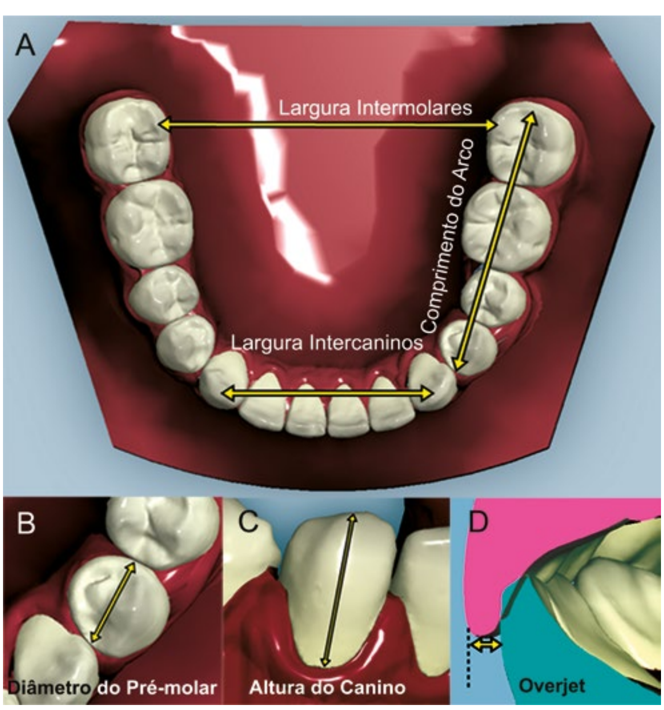

Figure 1 - Six measurements obtained in digital and plaster models. One can see the Intertermolar Width, Arc Length and Intercanine Width **(A)**, Premolar Diameter **(B)**, Canine Length **(C)** and Overjet **(D)** between the right upper central incisor and the right lower central incisor.

Statistical analysis

A sample size of 19 models per group would be necessary to detect a difference of 5% between the measurement in plaster model and in digital model in relation to the canine width, establishing a power of 80% and assuming a probability of 5% for a canine width of 7.20mm and a standard deviation of 0.38mm[11] (G*Power, Dusseldorf, Germany). The Shapiro-Wilk normality test was performed to verify the normal distribution of the data. Intraobserver systematic errors between the replicas were described as differences in absolute means and standard deviations and compared statistically with the Student's t-test for paired data. The intraobserver random error was estimated by the Intraclass Correlation Coefficient (ICC) and the Method Error . The differences between analog and digital measurements were evaluated by Student's t-test. In addition, Bland-Altman analysis was obtained to verify the agreement between both methods. Statistical analyses were performed by IBM SPSS™ software (version 25.0, SPSS, Armonk, NY) with a significance level of 0.05.

RESULTS

The results showed that systematic intraobserver errors in both methods were similar (Table 1). Of the twelve differences obtained, only two were statistically significant ($p<0.05$). The first measurement of the Arc Length performed in the plaster models was 0.313mm lower than the replica and the first measurement of the Intercanine Width performed in the digital models was 0.366mm larger than the replica. The Method Error ranged from 0.104mm to 0.414mm (Table 2). The mesio-distal distance of the first premolar and the Overjet showed the smallest difference (0.042mm) and the Arch Length showed the greatest difference (0.310mm) between the measurements of both methods.

	Modelos de gesso			eXceed™		
Medidas	Dif. (mm)	DP (mm)	Sig.	Dif. (mm)	DP (mm)	Sig.
Diâmetro do Pré-molar	-0,024	0,226	0,647	-0,015	0,166	0,691
Largura intercaninos	0,018	0,350	0,821	0,366	0,359	***<0,001***
Largura intermolares	-0,185	0,417	0,063	-0,110	0,357	0,186
Altura do canino	-0,056	0,227	0,288	0,056	0,339	0,473
Comprimento do arco	-0,313	0,509	0,013	0,047	0,142	0,156
Overjet	-0,010	0,229	0,855	0,054	0,159	0,148

***Italics* + bold** indicates significant statistical difference between the replicas ($p<0.05$).

Table 1 - Systematic intraobserver errors (mm) and significance (Sig) between the first and second replicas for each of the six protocols measured.

	Plaster models		eXceed™	
Measurements	ME (mm)	ICC	ME (mm)	ICC
Premolar Diameter	0,157	0,916	0,115	0,960
Intercanines width	0,242	0,994	0,358	0,987
Intermolars width	0,316	0,996	0,258	0,997
Canine height	0,161	0,990	0,237	0,978
Arc length	0,414	0,959	0,104	0,997
Overjet	0,158	0,987	0,116	0,992

Table 2 - Intraobserver random errors, estimates between replicas with Method Error (ME) and Intraclass Correlation Coefficient (ICC).

The plaster models presented four of the six measurements slightly higher than the digital method (Table 2). The ICC values ranged from 0.916 to 0.997 (high and consistent values), showing a slightly better correlation for the digital method (Table 2). Bland-Altman graphs showed that the differences in repeatability between the two methods were within the limits of agreement (Figure 2).

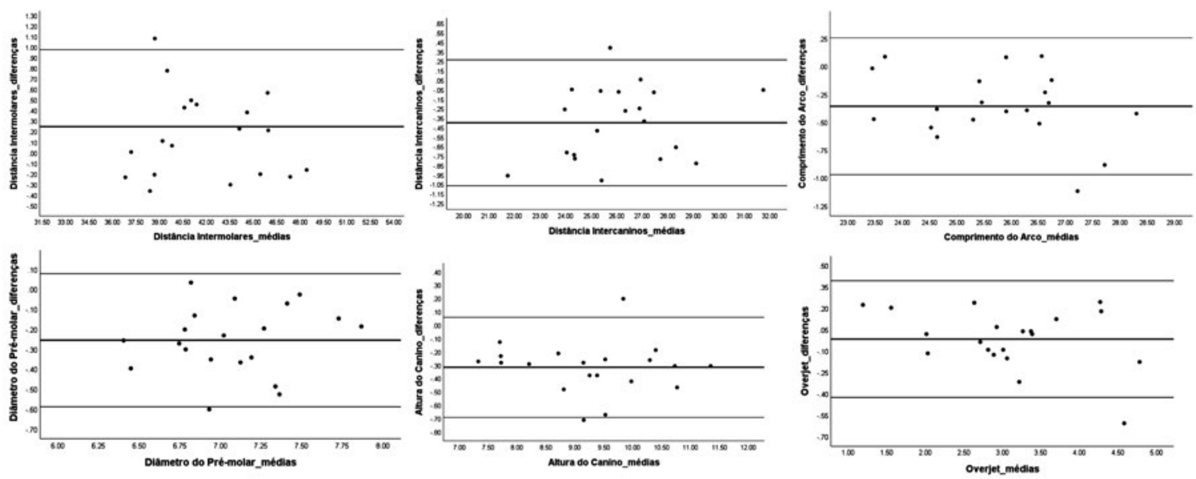

Figure 2 - Bland-Altman analysis of the six measurements of plaster and digital models. The differences were calculated from the subtraction between the replicas of the eXceed™ and manual methods.

When the two methods were compared, four of the six measurements showed statistically significant differences (Table 3). The differences in the measurements obtained were DP=0.253mm, ICW=0.396mm, CH=0.314mm and AL=0.359mm, values were higher when measured in the plaster model than when measured in the digital model.

	Plaster models		eXceed™		Plaster - eXceed™		
Measurements	**Average**	**DP**	**Average**	**DP**	**Dif.**	**DP**	**Prob.**
Premolar Diameter	7,206	0,382	6,951	0,408	0,253	0,170	***<0,001***
Intercanines width	26,298	2,162	25,902	2,253	0,396	0,391	***<0,001***
Intermolars width	41,978	3,583	42,102	3,515	-0,124	0,437	0,219
Canine height	9,432	1,154	9,118	1,136	0,314	0,192	***<0,001***
Arc length	25,931	1,132	25,572	1,335	0,359	0,313	***<0,001***
Overjet	3,091	0,992	3,077	0,919	0,014	0,208	0,759

Italics + **bold** indicate significant statistical difference between replicas (p<0.05).

Table 3 - Descriptive Statistics (mm) and systematic differences (mm) between measurements performed directly between plaster models and the corresponding 3D digital models, negative values indicate overestimated measurements in the digital method.

DISCUSSION

The values of manual and digital measurements proved to be accurate and precise representations. Although the measurements performed in both methods were subject to intraobserver variability, only two of the measurements showed statistically significant differences between the replicas and had approximate magnitude (AL=0.313mm and ICW=0.366mm). The systematic error was slightly higher than the previously reported errors[11,18,19], but clinically acceptable. Previous studies have reported that differences in measurements with values below 0.20mm have been shown to be clinically acceptable[20]we aimed to assess accuracy, scan time, and patient acceptance of a chairside oral scanner when used for full-arch scans; these are critical factors for acceptance of this technology in the orthodontic setting.\nMethods Fifteen patients had digital models made from both intraoral scans (Lava COS; 3M ESPE, St Paul, Minn. Systematic intraobserver differences should not occur if the individual is adequately calibrated and if the measurement method is standardized.

The measurements performed on digital models in the eXceed™ system were highly accurate. The eXceed™ produced smaller random errors than the conventional method performed in plaster models with the digital caliper. The lowest values obtained from ICC were 0.960 and 0.916 for the digital model and plaster model, respectively. Jacob et al[11] (2015) used intra and extraoral scanners and demonstrated similar ICC values. Other studies have shown high coefficient values of ICC based on virtual models[13,21–23]. Considering that the reliability coefficient above 0.75 was considered optimal[24], the values of ICC substantially higher obtained in this study indicated excellent precision and accuracy in both methods.

Both methods (caliper and eXceed™) showed high agreement. The Bland-Altman graph showed that more than 95% of the differences between the two methods were within a standard deviation with the differences in agreement limit ranging from 0.67mm to 1.70mm (Figure 2). The differences were relatively low and it can be suggested that the digital method can safely replace the analog method. Akyalcin et al.[21] showed almost perfect agreement between intraoral scan and measurements obtained using a caliper. Jacob et al[11] (2015) evaluated three scanners (two intraoral and one table) and compared with the measurements obtained from the caliper and found high agreement between the scanners. Literature clearly shows that scanners and digital measurements can replace conventional plaster models and measurements obtained by paquimeters[9,10,13-18,20-22,25,26]reliability, and reproducibility of digital models obtained from the Lava Chairside Oral scanner (3M ESPE, Seefeld, Germany.

The measurements obtained from digital models were compared with the same measurements obtained directly from the plaster models. On average, digital measurements were slightly lower than manual measurements, with differences ranging from 0.01mm to 0.40mm. The eXceed system™ was not previously evaluated, making comparisons difficult. Comparative studies between plaster and digital models found significant differences between the methods, but without restrictions for clinical use[14–17,23,26]maxillary and mandibular. Müllen et al[17] and the time to perform a Bolton analysis for each patient by using software (emodel, version 6.0, GeoDigm Corp, Chanhassen, Minn found differences in Arc Length between plaster models and emodels™ software, the authors showed greater Arc Length in plaster models than in digital models[17]and the time to perform a Bolton analysis for each patient by using software (emodel, version 6.0, GeoDigm Corp, Chanhassen, Minn. According to previous studies, the discrepancy in measurements below 0.4mm are not clinically significant[5,18,23]. Our results showed that only the measurements of Intermolar Width in digital models were slightly higher than those performed in plaster models, but without clinical significance ($p>0.05$). Jacob et al[11] (2015) found that most measurements in dry jaws were overestimated when compared to the same measurements in digital models of three different scanners. Interestingly, the authors found a statistically significant difference when the measurements were performed in dry jaws (two out of fifteen) and were higher than the same measurements obtained in digital models. Although the operator can view the models at different angles, the differences between the digital and plaster models may be related to the difficulty in measuring a 3D object in two dimensions on a computer screen[20]we aimed to assess accuracy, scan time, and patient acceptance of a chairside oral scanner when used for full-arch scans; these are critical factors for acceptance of this technology in the orthodontic setting.\nMethods Fifteen patients had digital models made from both intraoral scans (Lava COS; 3M ESPE, St Paul, Minn. Depending on the operator's training, skills and preferences, the measurement performed on a computer screen may be more or less accurate than the conventional method with the use of a caliper in plaster models[14,16].

Although no reference marking has been created in plaster models to enable greater credibility in relation to possible errors, the results of this study have limitations due to the use of plaster models and table scanner instead of dry jaws and/or measurements directly from the mouth and use of intraoral scanners. It is possible that the plaster models may have suffered some involuntary marking by the tip of the caliper. For this reason, the demarcated point would facilitate access to new measurements due to wear, although the measurements were performed with a time interval between the replicas. Therefore the observer when comparing the measurements of both methods may have been more accurate. In addition, table scans are more accurate than intraoral scans[27], because there is no interference of soft tissue and saliva in the region to be scanned and the object remains static, avoiding distortions in the generated image. Another limitation was the use of a version of a specific software, although the objective of this study was the validation of eXceed™ software for clinical use, as it allows a quick and easy to understand management by clinicians.

CONCLUSIONS

Based on the results obtained and within the limitations of this study, we conclude that:

1. The measurements obtained from the plaster models were slightly higher than the digital ones, excluding Overjet which was practically zero; the Intermolar Width in digital models was slightly higher than in plaster models.

2. The measurements performed in both methods were reliable and reproducible, although the digital models were slightly more accurate.

3. The validity of the measurements obtained from the eXceed™ digital models, compared with those obtained from plaster models, indicated that both methods are acceptable for daily clinical practice.

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