J Orofac Orthop (2017) 78:394–402
DOI 10.1007/s00056-017-0093-1

ORIGINAL ARTICLE

Accuracy of stereolithographically printed digital models compared to plaster models

Genauigkeit von stereolitographisch gedruckten digitalen Modellen im Vergleich zu Gipsmodellen

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Received: 17 October 2016 / Accepted: 1 March 2017 / Published online: 30 March 2017
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Abstract
Objective This study compared the accuracy of plaster models from alginate impressions and printed models from intraoral scanning.
Materials and methods A total of 28 volunteers were selected and alginate impressions and intraoral scans were used to make plaster models and digital models of their dentition, respectively. The digital models were printed using a stereolithographic (SLA) 3D printer with a horseshoe-shaped design. Two calibrated examiners measured distances on the plaster and printed models with a digital caliper. The paired *t* test was used to determine intraobserver error and compare the measurements. The Pearson correlation coefficient was used to evaluate the reliability of measurements for each model type.
Results The measurements on plaster models and printed models show some significant differences in tooth dimensions and interarch parameters, but these differences were not clinically relevant, except for the transversal measurements. The upper and lower intermolar distances on the printed models were statistically significant and clinically relevant smaller.
Conclusions Printed digital models with the SLA 3D printer studied, with a horseshoe-shaped base made from intraoral scans cannot replace conventional plaster models from alginate impressions in orthodontics for diagnosis and treatment planning because of their clinically relevant transversal contraction.

Keywords Intraoral scanning · Digital dental models · Printed models · Accuracy

Zusammenfassung
Ziel In der vorliegenden Studie sollte die Genauigkeit von nach Alginatabdrücken erstellten Gipsmodellen mit nach intraoralen Scans gedruckten Modellen mit einem SLA 3D printer verglichen werden.
Material und Methoden Von insgesamt 28 freiwilligen Probanden wurden Alginatabdrücke und intraorale Scans für Gipsmodelle bzw. digitale Modelle angefertigt. Die digitalen Modelle wurden mit einem 3-D-Stereolithographie-Drucker (SLA) mit hufeisenförmigem Design erstellt. Nach Kalibrierung werteten zwei Untersucher beide Modelltypen mit einer digitalen Schieblehre aus. Der gepaarte *t*Test wurde zur Ermittlung des Intrauntersucher-Fehlers und zum Vergleich der Messungen, der Korrelationskoeffizient nach Pearson zur Evaluierung der Messreliabilität für jeden Modelltyp verwandt.
Ergebnisse Die Messungen an beiden Modellarten zeigen einige signifikante Unterschiede bei dentalen Dimensionen und Kieferbogenparameter, mit Ausnahme der Quermessungen waren diese jedoch nicht von klinischer Relevanz. In den 3-D-Druck-Modellen waren obere wie untere intermolaren Distanzen statistisch signifikant und klinisch relevant geringer.
Schlussfolgerungen Wegen der Querkontraktion können anhand von intraoralen Scans gedruckte digitale Modelle mit einer hufeisenförmigen Basis die konventionellen

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Gipsmodelle nach Alginatabdrücken bei der kieferorthopädischen Diagnostik- und Behandlungsplanung nicht ersetzen.

Schlüsselwörter Intraorales Scannen · digitale Zahnmodelle · gedruckte Modelle · Genauigkeit

Introduction

Orthodontic diagnosis, treatment planning, and evaluation of treatment changes are traditionally performed on plaster models made from alginate impressions. However, plaster models are heavy and bulky, liable to damage and it is difficult to share these models with other professionals involved in the dental care of patients. Storage of the models requires office space and retrieval takes handling time for assistants. Storage of all patient records after the completion of treatment for many years is by law compulsory [21]. The use of digital models, which can be made by scanning plaster models or impressions can be an alternative for physical dental models [4, 6, 13, 16, 20, 21, 26, 31, 36]. Intraoral scanning of the dentition is a direct method of digital dental model acquisition and research has been published showing that the intraoral scanning method is accurate and digital dental models from intraoral scans can replace plaster models [9, 12, 28, 34]. As 3D printers can be used to print digital dental models, it is now possible to obtain a physical copy of a digital dental model in an easy and inexpensive way [3, 17, 19, 21]. The "rapid prototyping" 3D printing technique was introduced in the 1980s for the manufacturing of physical models. CAD–CAM (computer-aided design, computer-aided manufacturing) techniques have been used for planning of maxillofacial surgery, printing of surgical splints, and guides for placement of dental implants and temporary anchorage devices (TADs) such as miniscrews [1, 5, 14, 18, 24, 35]. These techniques are also used for implantology and prosthetic dentistry. In orthodontics, CAD–CAM procedures are used for design and fabrication of custom orthodontic appliances such as custom brackets and wires and indirect bonding trays [8]. For several decades, these procedures have been used to make a set of aligners made on printed models which can be used for orthodontic treatment [23], and the digital design and fabrication of retainers for orthodontic patients was recently introduced [3].

A physical model is sometimes still needed, as some orthodontists prefer physical models over digital dental models because they are required for the traditional method of appliance fabrication. Printed dental models in acrylic material have a low weight and there is a low probability of fracturing. Printed models are durable and have a high resistance to abrasion. There are several printers available that can print various 3D objects. The most commonly used printers are FDM (fusion deposition modeling) printers. In the process of printing, thin plastic lines are positioned on a template to build a plastic object. Powder-based printers melt nylon or a similar type of thermoplastic powder with a laser beam. Stereolithographic (SLA) is another method of 3D printing. In the SLA technique, a photosensitive liquid resin bath, a model-building platform, and an ultraviolet laser light is used to cure layers of resin to form a solid object such as a dental model [19, 32]. Advantages of the SLA printing process include the following: high part-building accuracy, a smooth surface finish, fine building details, and high mechanical strength. Before they can be used in dentistry, the accuracy and reliability of printed models should be tested. Only a few studies on the accuracy of printed models in orthodontics have been published [17, 19, 21]. The sample of printed models used in these studies was relatively small with only one pair of models [21], six pairs [17], and ten pairs [19]. These studies concluded that the 3D (prototyped) dental models are sufficiently accurate to be used in orthodontics and can replace plaster models.

The aim of this current study is to compare measurements made on printed models with the SLA printing process made after intraoral scanning of the dentition of volunteers to measurements on a sample of plaster models (the gold standard), acquired from alginate impressions of the dentition of the same subjects.

Materials and methods

Applying the formula described by Pandis [29] assuming 90% power and an α of 0.05, plaster models of 10 randomly selected individuals were used for a power study. This study revealed that at least 28 plaster models and intraoral scans of patients were needed to reveal a 1-mm

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difference in measurements with a 1.16 mm standard deviation. A series of volunteers were recruited at the Department of Orthodontics of Federal Fluminense University. A total of 28 volunteers who met the inclusion criteria were included. Inclusion criteria were fully erupted permanent dentition (including all upper and lower first permanent molars). Exclusion criteria were marked dental anomalies in size and shape, severe gingival recessions, severe dental crown abrasions, attritions and erosions, or fixed orthodontic retention. At the time of impression taking, the volunteers were between 21 and 39 years of age (average age 27 years). All volunteers were informed about the study procedures and signed the informed consent. The local ethical committee approved this study (number 1.663.692) on 22 July 2016.

Participants underwent a clinical examination and alginate impressions of the upper and lower arch were made with Hydrogum® (Zhermack, Badia Polesine, Rovigo, Italy) alginate, following the manufacturer's guidelines. Within 1 h, the teeth and alveolar ridges in the alginate impressions were filled with type IV plaster (Vigodent, Rio de Janeiro, Brazil) and the base was filled with white plaster (Mossoró, Rio de Janeiro, Brazil) (Fig. 1a). The wax bite registration of the occlusion was obtained with a number 7 dental wax (Clássico, São Paulo, Brazil) and used to trim the base of the plaster models. The volunteers underwent intraoral scanning of their dentition with the TRIOS Color scanner (3Shape®, Copenhagen, Denmark), following the manufacturer's instructions. The upper arch was scanned first, then the lower arch was scanned; thereafter, the volunteer was instructed to occlude in maximum intercuspation to enable scanning of the occlusion on both the right and left sides of the arches. The scanner software positioned the dental arches in occlusion. After completion of the scanning procedure, the stereolithography files (STL files) of the scan were stored in the research computer.

The STL files were exported to the Appliance Designer software (3Shape®, Copenhagen, Denmark) to create digital models with a horseshoe-shaped base. The digital models were transferred by internet to the OrthoProof company (Nieuwegein, The Netherlands) to be printed with a 3D printer. A digital light processing 3D SLA printer (Ultra, Envisiontec, Gladbeck, Germany), containing a light curing methacrylic resin (RC31, Envisiontec, Gladbeck, Germany), was used to print the physical dental models with a build layer thickness of 0.10 mm (Fig. 1b). The printed models in this study were postcured with a 400 W ultraviolet lamp for 20 s to completely cure the resin.

A total of 52 predefined distances (Table 1) were measured on the dental models by two trained and calibrated examiners. Measurements on plaster and printed models were made with a digital caliper (Tesa SA, Renens, Switzerland). Before the beginning of measuring, both examiners measured all the parameters on five pairs of models of the randomly selected sample and measured these same models again after 15 days to evaluate the accuracy and reliability of the measurements between the examiners. After this calibration process, the examiners started to measure all the models.

To investigate the intraexaminer performance, after the measurements of all 30 pairs of models of the sample, the measurements on 10 sets of models (randomly selected), were repeated after 15 days by both examiners.

Statistical analysis

Statistical analyses were performed using the SPSS program, version 20.0 (IBM, Chicago, IL, USA). The paired *t*-test was used to determine intraexaminer performance and to compare the measurements made on plaster models and printed models from each of the two examiners. The Pearson correlation coefficient was calculated to evaluate the examiner reliability of measurements for each model type. *P*-values <0.05 were considered to be significant. In this study, the same criteria for clinically relevant differences as described in the literature were used [11, 28, 34]. Differences more than

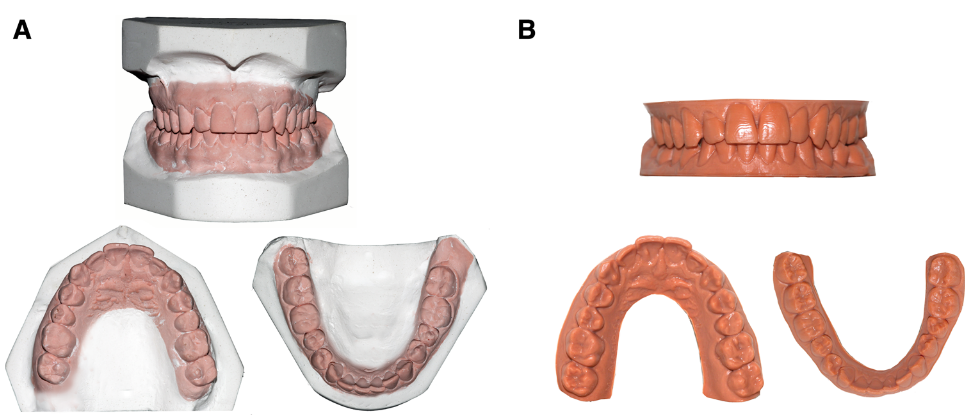

Fig. 1 **a** Plaster model with a regular base, **b** printed model with a horseshoe-shaped base
Abb. 1 **a** Gipsmodell mit regulärer Basis, **b** gedrucktes Modell mit hufeisenförmiger Basis

Tab. 1 Parameter definitions
Tab. 1 Definitionen der Parameter

Parameter	Abbreviation	Definition
Mesiodistal diameter	MDD	Upper and lower mesiodistal diameter of each tooth from 1st molar to 1st molar (largest mesiodistal diameter of the mesial contact point to the distal contact point, parallel to the occlusal plane)
Sum of upper 6 teeth	Sum upper 6	Diameter sum of 6 anterior upper teeth
Sum of upper 12 teeth	Sum upper 12	Diameter sum of 12 anterior upper teeth
Sum of lower 6 teeth	Sum lower 6	Diameter sum of 6 anterior lower teeth
Sum of lower 12 teeth	Sum lower 12	Diameter sum of 12 anterior lower teeth
Crown height	CH	Upper and lower crown height of upper and lower 1st molars, 1st premolars, canines and central incisors (from incisal edge or cusp tip to the lower gingival margin from the vestibular axis of each clinical crown—Andrews)
Upper intercanine distance	Upper ICD	Distance between the cusp tip of the upper left canine to the cusp tip of the upper right canine
Upper intermolar distance	Upper IMD	Distance between the tip of the mesiobuccal cusp of the upper left 1st molar to the tip of the mesiobuccal cusp of the upper right 1st molar
Lower intercanine distance	Lower ICD	Distance between the cusp tip of the lower left mandibular canine to the cusp tip of the lower right canine
Lower intermolar distance	Lower IMD	Distance between the tip of the mesiobuccal cusp of the lower left 1st molar to the tip of the mesiobuccal cusp of the lower right 1st molar
Overjet	Overjet	Distance from the middle of the incisal edge closest to the buccal surface of the upper right maxillary central incisor to the buccal surface of the lower incisor antagonist, parallel to the occlusal plane
Overbite	Overbite	Vertical distance between the marking where the incisal edge of the upper right central incisor overlaps the buccal surface of the lower incisor antagonist until its respective incisal edge
Interarch right sagittal relationship	Right Sag Rel	Distance from the cusp tip of the upper right canine to the meeting point between the gingival margin and the extension of the mesiobuccal groove of the lower right 1st molar
Interarch left sagittal relationship	Left Sag Rel	Distance from the cusp tip of the upper left canine to the meeting point between the gingival margin and the extension of the mesiobuccal groove of the lower left 1st molar

0.3 mm for the overjet, overbite, and tooth size (tooth diameter and tooth height) and more than 0.4 mm for transversal and sagittal measurements were considered to be clinically relevant [11, 28]. For differences in the sum of 6 anterior teeth in the upper or lower dental arch, a threshold of 0.75 mm and for the sum of 12 teeth in the upper or lower arch a difference of 1.5 mm was used as criteria for clinical relevant differences [34].

Results

The intraexaminer error comparison showed an excellent accuracy of measurements; a few measurements with statistically significance differences and one parameter with a clinically relevant difference was found for each examiner (Table 2). The Pearson correlation showed an intraexaminer reliability of 0.975 on average by both examiners. The comparison between the measurements on plaster models and printed models showed some statistical differences in tooth dimensions (diameter and crown height) and interarch parameters (overjet, overbite and sagittal relationship) but no clinically relevant measurements. According to the measurements of both examiners, the transversal distances between the upper and lower molars were both statistically and clinically relevant smaller on the printed models compared to the plaster models (Table 3).

Discussion

Several studies concluded that digital models are accurate and can be used to replace plaster models. Different methods of acquisition of digital models such as plaster model scanning, alginate and polyvinylsiloxane (PVS) impression scanning and intraoral scanning were tested [2, 6, 9, 10, 12, 13, 15, 20, 22, 25, 26, 28, 30, 31, 33, 34, 36]. A direct technique such as the intraoral scanning method can reduce some impression inaccuracy caused during the traditional procedure of impression taking and plaster model manufacturing, such as air bubbles, rupture of impression material, inaccurate impression tray dimensions, too much or too little impression material, inappropriate adhesion of the impression to the impression tray,

Tab. 2 Intraexaminer performance of examiners 1 and 2 according to the paired *t*-test and the Pearson correlation coefficient (reliability)
Tab. 2 Intrauntersucher-Performance der Untersucher 1 und 2, ermittelt anhand dem gepaartem t-Test und dem Pearson-Korrelationskoeffizienten (Reliabilität)

Parameter[a]	Examiner 1								Examiner 2							
	Plaster model				Printed model (horseshoe-shaped base)				Plaster model				Printed model (horseshoe-shaped base)			
	Reliability	MD (mm)	SD (mm)	*p*	Reliability	MD (mm)	SD (mm)	*p*	Reliability	MD (mm)	SD (mm)	*p*	Reliability	MD (mm)	SD (mm)	*p*
Sum 6 upper teeth	0.976	0.123	0.479	0.438	0.975	0.011	0.579	0.953	0.982	0.655	0.394	**0.001**	0.996	0.392	0.240	**0.001**
Sum 12 upper teeth	0.980	0.870	0.859	**0.011**	0.990	–0.034	0.654	0.873	0.988	0.790	0.668	**0.005**	0.999	0.572	0.274	**0.000**
Sum 6 lower teeth	0.992	–0.003	0.280	0.974	0.959	–0.121	0.634	0.561	0.983	0.493	0.462	**0.008**	0.982	0.299	0.447	0.063
Sum 12 lower teeth	0.988	0.598	0.715	**0.027**	0.983	–0.316	0.846	0.268	0.993	0.847	0.594	**0.001**	0.992	0.506	0.620	**0.030**
CH 16	0.958	–0.021	0.353	0.855	0.987	0.071	0.152	0.174	0.969	0.073	0.261	0.399	0.995	–0.007	0.100	0.830
CH 14	0.962	–0.079	0.266	0.372	0.935	0.121	0.291	0.221	0.973	–0.017	0.211	0.805	0.994	0.051	0.083	0.085
CH 13	0.988	0.062	0.167	0.270	0.989	–0.012	0.147	0.802	0.977	–0.061	0.200	0.361	0.998	0.084	0.068	**0.004**
CH 11	0.992	0.034	0.138	0.454	0.997	0.029	0.081	0.285	0.991	–0.011	0.145	0.815	0.997	0.041	0.072	0.104
CH 21	0.867	0.171	0.449	0.259	0.993	–0.043	0.096	0.191	0.989	0.059	0.136	0.203	0.996	0.014	0.069	0.539
CH 23	0.995	0.021	0.092	0.487	0.993	0.131	0.118	**0.006**	0.992	0.059	0.112	0.130	0.999	0.106	0.061	**0.000**
CH 24	0.977	0.059	0.223	0.424	0.995	0.053	0.127	0.219	0.992	0.061	0.137	0.192	0.998	0.058	0.071	**0.029**
CH 26	0.983	0.184	0.217	**0.025**	0.975	–0.082	0.244	0.316	0.944	0.131	0.502	0.431	0.993	–0.010	0.132	0.816
CH 36	0.922	0.097	0.306	0.343	0.928	0.093	0.296	0.346	0.905	0.217	0.326	0.064	0.994	–0.017	0.081	0.525
CH 34	0.812	–0.205	0.558	0.276	0.990	0.066	0.109	0.088	0.971	0.049	0.194	0.446	0.993	0.038	0.104	0.278
CH 33	0.989	–0.042	0.192	0.508	0.994	0.042	0.142	0.375	0.997	–0.020	0.097	0.530	0.997	0.032	0.102	0.347
CH 31	0.989	0.018	0.125	0.659	0.992	–0.006	0.130	0.887	0.989	0.028	0.129	0.511	0.996	–0.038	0.077	0.153
CH 41	0.986	0.006	0.149	0.902	0.991	–0.020	0.116	0.600	0.992	0.012	0.112	0.742	0.996	0.033	0.083	0.239
CH 43	0.959	–0.100	0.248	0.234	0.964	–0.039	0.221	0.590	0.990	–0.037	0.116	0.339	0.994	0.006	0.103	0.857
CH 44	0.980	–0.014	0.181	0.812	0.962	0.055	0.227	0.463	0.852	0.380	0.475	**0.032**	0.992	0.008	0.100	0.805
CH 46	0.925	–0.050	0.236	0.519	0.943	–0.067	0.183	0.276	0.914	0.029	0.294	0.762	0.973	0.004	0.120	0.918
Upper ICD	0.984	–0.009	0.321	0.931	0.987	0.086	0.303	0.392	0.968	0.165	0.468	0.294	0.996	0.199	0.175	**0.006**
Lower ICD	0.967	0.058	0.456	0.697	0.977	0.026	0.379	0.833	0.982	–0.176	0.334	0.130	0.992	0.011	0.253	0.894
Upper IMD	0.979	0.229	0.504	0.185	0.986	–0.016	0.426	0.908	0.997	–0.064	0.206	0.352	0.998	0.044	0.166	0.423
Lower IMD	0.968	–0.185	0.599	0.355	0.978	0.107	0.544	0.550	0.987	0.164	0.465	0.294	0.998	0.081	0.225	0.285
Overjet	0.962	0.317	0.189	**0.000**	0.873	–0.141	0.316	0.192	0.970	0.074	0.185	0.237	0.987	0.020	0.111	0.583
Overbite	0.981	0.117	0.204	0.104	0.974	0.012	0.230	0.873	0.977	0.074	0.240	0.356	0.994	–0.009	0.118	0.815

Tab. 2 continued

Parameter[a]	Examiner 1								Examiner 2							
	Plaster model				Printed model (horseshoe-shaped base)				Plaster model				Printed model (horseshoe-shaped base)			
	Reliability	MD (mm)	SD (mm)	p	Reliability	MD (mm)	SD (mm)	p	Reliability	MD (mm)	SD (mm)	p	Reliability	MD (mm)	SD (mm)	p
Right Sag Rel	0.960	0.173	0.430	0.235	0.957	0.249	0.376	0.066	0.957	0.019	0.392	0.882	0.985	–0.019	0.202	0.773
Left Sag Rel	0.939	0.325	0.526	0.083	0.952	0.368	0.502	**0.046**	0.970	–0.233	0.376	0.082	0.995	–0.049	0.165	0.371

p value < 0.05

MD mean difference, *SD* standard deviation

[a] Abbreviations/parameters this table are defined in Table 1

disinfection of the impression and distortion of the impression material during storage [33]. An advantage of the intraoral scanning procedure is the direct registration of the occlusion as an indirect occlusion registration method with a wax bite or PVS material is not required.

Digital models can be stored on computers in the dental or orthodontic office and a copy of the models can be kept "in the cloud". Printed models can serve as a "hard copy" of the scanned data. This study compared the accuracy of plaster models from alginate impressions with printed models from intraoral scanning of the dentition using the SLA printing method. Other studies that evaluated the accuracy of printed models with the SLA technique reported that the printed models were accurate and reliable, but the sample used in these studies was relatively small and all the printed models presented a regular base (American Board of Orthodontics base) [17, 19, 21]. In the current study, measurements on 28 plaster and printed models were compared. The printed models had a horseshoe-shaped base because they were prepared for aligner fabrication. Hazeveld et al. [17] evaluated the accuracy of three rapid prototyping techniques: digital light processing (liquid based; Envisiontec, Gladbeck, Germany), jetted photopolymer (liquid based; Objet Geometries, Rehovot, Israel), and 3D printing (powder based; Z-Corp, Rock Hill, SC, USA). Their results showed that differences between the measurements on plaster models and printed models with these three techniques were small and clinically insignificant (less than 0.25 mm). Kasparova et al. [19] investigated the accuracy of linear measurements between 10 pairs of plaster models, 10 pairs of printed models with the low cost RepRap 3D printer (The Czech Republic) which uses FDM technique, and 1 pair of printed models with the ProJet HD3000 3D printer (3D Systems, USA) that uses Multi-Jet Modeling technology. No significant differences were found between the tested models. Keating et al. [21] reported that translucency of printed models makes landmark identification on printed models for measurement difficult because of loss of surface detail, particularly at the cervical margin region. As the models used in our study were printed with a colored material, we did not have this measurement indication problem. The same measurement technique was used to measure both plaster and printed models, i.e., a digital caliper, which was validated as a reliable method for other studies [17, 19, 21].

The results of this study showed no clinically relevant differences in the measurements of teeth dimensions (mesiodistal diameter and crown height) between the plaster and printed models. In addition, the interarch relationship (overjet, overbite, and sagittal relationship) did not reveal any clinically relevant difference between printed and plaster models, but the transversal dimensions, especially the upper and lower intermolar distances, presented a

Tab. 3 Comparison between plaster model and printed models with horseshoe-shaped base according to the paired *t*-test and the Pearson correlation coefficient (reliability)

Tab. 3 Vergleich zwischen Gipsmodellen und gedruckten Modellen mit hufeisenförmiger Basis mittels gepaartem T-Test und Pearson-Korrelationskoeffizienten (Reliabilität)

Parameter[a]	Examiner 1				Examiner 2			
	Reliability	MD (mm)	SD (mm)	*p*	Reliability	MD (mm)	SD (mm)	*p*
Sum 6 upper teeth	0.926	–0.201	0.959	0.276	0.928	–0.035	0.939	0.844
Sum 12 upper teeth	0.964	–0.640	1.284	**0.014**	0.961	–0.042	1.321	0.868
Sum 6 lower teeth	0.957	–0.336	0.568	**0.004**	0.939	–0.138	0.685	0.296
Sum 12 lower Teeth	0.979	–0.933	0.849	**0.000**	0.965	–0.037	1.046	0.854
CH 16	0.926	–0.160	0.335	**0.018**	0.895	–0.056	0.397	0.461
CH 14	0.965	–0.160	0.242	**0.002**	0.936	–0.121	0.323	0.057
CH 13	0.946	–0.031	0.285	0.564	0.952	–0.128	0.263	**0.016**
CH 11	0.932	–0.218	0.348	**0.003**	0.935	–0.104	0.334	0.111
CH 21	0.929	–0.109	0.370	0.131	0.923	0.001	0.384	0.984
CH 23	0.937	–0.200	0.324	**0.003**	0.928	–0.123	0.333	0.061
CH 24	0.969	–0.105	0.256	**0.038**	0.964	–0.008	0.275	0.887
CH 26	0.950	–0.005	0.284	0.932	0.977	0.049	0.200	0.206
CH 36	0.893	–0.036	0.337	0.580	0.823	0.039	0.466	0.659
CH 34	0.917	–0.173	0.371	**0.020**	0.964	–0.060	0.254	0.222
CH 33	0.976	–0.065	0.272	0.219	0.983	0.034	0.232	0.451
CH 31	0.953	–0.129	0.261	**0.014**	0.950	–0.023	0.276	0.670
CH 41	0.946	–0.020	0.251	0.676	0.940	0.028	0.262	0.583
CH 43	0.954	–0.068	0.326	0.278	0.948	0.006	0.351	0.932
CH 44	0.959	–0.153	0.268	**0.005**	0.967	0.029	0.238	0.525
CH 46	0.928	–0.114	0.295	0.051	0.885	–0.076	0.366	0.282
Upper ICD	0.975	0.322	0.415	**0.000**	0.848	0.092	1.308	0.713
Lower ICD	0.961	0.320	0.454	**0.001**	0.887	0.023	0.841	0.888
Upper IMD	0.992	0.683	0.407	**0.000**	0.989	0.834	0.489	**0.000**
Lower IMD	0.962	0.681	0.701	**0.000**	0.930	0.579	1.050	**0.007**
Overjet	0.901	–0.031	0.401	0.682	0.873	0.025	0.441	0.766
Overbite	0.905	–0.224	0.363	**0.003**	0.906	–0.240	0.371	**0.002**
Right Sag Rel	0.943	0.185	0.577	0.101	0.907	–0.066	0.810	0.671
Left Sag Rel	0.969	0.083	0.440	0.328	0.943	0.111	0.537	0.285

p value < 0.05

MD mean difference, *SD* standard deviation

[a] Abbreviations/parameters are defined in Table 1

clinically relevant reduction in printed models measured by both examiners.

The SLA printing technique is not capable of curing the printing material completely during the printing time. The explanation of these clinically relevant differences in transversal distances may be caused by the "post cure" process which is needed for printed models with the SLA technique. It has been published that model shrinkage during building and postcuring as well as the residual polymerization and transformation of photocured materials can cause differences in the accuracy of printed objects [7, 17, 21].

Some orthodontic labs use printed models without a regular base to reduce printing time and to save resin material. The horseshoe-shaped base as used in this study facilitates aligners manufacturing with plastic sheets and pressure molding machines. The use of models with a horseshoe-shaped base printed with the SLA printer used in this study and postcured with UV laser light can result in not only inaccurate analysis and treatment planning, but also inaccurate appliances made on these printed models due to their transversal contraction in the posterior region. Further studies are needed to evaluate the effect of a different model base design or a different printing technique on the accuracy of printed models.

Limitations of the intraoral scanning method and rapid prototyping technology currently include the high cost of the devices, the printing material, and relatively complicated software for CAD–CAM procedures. The printing material for dental models has a bad odor, is toxic, and must be shielded from light to avoid premature polymerization [27]. Digital appliance design and subsequently printing or milling of an orthodontic appliance without the need for physically printed models has been introduced. A further increase in efficiency and accuracy of intraoral scanning methods and a decrease of the costs of printing of dental models and dental appliances can be expected.

Conclusions

Although most dental dimensions of the plaster and printed models measured with a digital caliper were clinically not significantly different, the printed models with the SLA technique using a horseshoe-shaped base from intraoral scanning of the dentition cannot replace conventional plaster models made from alginate impressions in orthodontics due to their clinically relevant reduced transversal dimensions in the posterior region. More studies are needed to evaluate the accuracy of the process of intraoral scanning and digital model printing in orthodontics.

Acknowledgements We would like to thank the "National Counsel of Technological and Scientific Development" (CNPq) for the scholarship for the first author of this study and to the OrthoProof® company for printing the models used in this study.

Compliance with ethical guidelines

Conflict of interest LT. Camardella, O.V. Vilella, M.M. van Hezel, and K.H. Breuning declare that they have no competing interests.

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