Scripta Scientifica Medicinae Dentalis, 2023;9(2):42-60
DOI: 10.14748/ssmd.v9i2.9242

ISSN 2367-7236 (Print)
ISSN 2367-7244 (Online)

ORIGINAL ARTICLES

ACCURACY AND RELIABILITY OF LOWER DENTAL ARCH RECONSTRUCTIONS

Konstantin Kostadinov, Stefan Peev

Department of Periodontology and Dental Implantology, Faculty of Dental Medicine, Medical University of Varna, Bulgaria

ABSTRACT

INTRODUCTION: In the literature, there is information regarding the accuracy of models generated by conventional impression materials and intraoral scanners, but data on the accuracy of 3D models generated from cone-beam computed tomography (CBCT) is still lacking.

AIM: The aim of this article is to investigate and compare the accuracy of tooth reconstructions made on 3D models generated from CBCT and intraoral scanning, as well as on plaster models from conventional impression materials, to the results of intraoral measurements using a digital caliper.

MATERIALS AND METHODS: The study included a total of 38 individuals (16 males and 22 females). After the initial examination, we scheduled appointments for the approved participants to undergo clinical procedures and imaging studies in the following sequence: 1. placement of composite markers; 2. physical measurements; 3. intraoral scanning; 4. CBCT; 5. capturing a conventional impression; 6. removal of composite markers.

Following are the laboratory and measurement stages for the study: 7. casting gypsum models; 8. measurements on gypsum models; 9. converting the DICOM files from CBCT scans to STL files; 10. conducting measurements on digital models from CBCT and intraoral scanning.

RESULTS: Results from the reliability assessment of the researcher's measurements for the studied modalities indicate a correlation coefficient ranging from moderate to excellent with very high statistical significance. Concerning accuracy, differences are observed between individual modalities.

CONCLUSION: In summary, conventional methods and materials still outperform intraoral scanners in terms of the accuracy of the obtained reconstructions. 3D models generated from CBCT scans are generally the least satisfactory among the tested modalities, with deviations typically within clinically acceptable values.

Keywords: *intraoral scanner, cone-beam computer tomography, conventional impression, accuracy, comparison*

Address for correspondence:
Konstantin Kostadinov
Faculty of Dental Medicine
Medical University of Varna
84 Tzar Osvoboditel Blvd
9002 Varna
e-mail: constantin633.91@gmail.com

Received: August 8, 2023
Accepted: September 30, 2023

INTRODUCTION

Dental medicine is advancing at an exceptionally fast pace, and one of the main reasons for this is the integration of digital technologies across its various fields (1,2). For instance, intraoral scanners, as an alternative to conventional impression techniques and materials (3) and the increasing use of cone-beam computed tomography (CBCT) scanners for everyday dental practice needs (4) exemplify this trend.

However, in everyday practice, conventional methods, materials, and techniques are still widely used. A clear example is the use of impression materials, which are still commonly utilized. With the help of taken impressions, we can obtain plaster models that are replicas of the patient's clinical situation, serving as a tool for more precise treatment planning and execution. Additionally, these models play a fundamental role in facilitating the communication between dental practitioners and dental laboratories.

Due to technological progress, various intraoral scanners (IOSs) are increasingly available on the market, offering the possibility to obtain digital models as an alternative to conventional methods. Working with IOS offers several advantages (5). The accuracy of various materials and modalities for taking impressions has been widely discussed by different authors, and to date, there is no unanimous consensus on whether conventional or digital techniques are more accurate.

Digital technologies also significantly influence the field of dental imaging diagnostics. With the introduction of CBCT, the possibilities for diagnosis, planning, and treatment in all areas of dental medicine have expanded. Volume visualization programs allow the construction of 3D models from CBCT data using algorithms typically unique to each program. The resulting 3D reconstructions (3D volume rendering) enable actions such as landmark identification, measurements, bone fragment manipulation, and virtual osteotomies. Therefore, the accuracy of the obtained model is of paramount importance not only for diagnostic purposes but also for treatment planning and its outcomes.

AIM

The aim of this article is to investigate and compare the accuracy of dental arch reconstructions made on 3D models generated from CBCT and intraoral scanning, as well as on plaster models from conventional impression materials, to the results of intraoral measurements using a digital caliper.

MATERIALS AND METHODS

The clinical study was conducted after obtaining approval from the Ethics Committee for Scientific Research at MU-Varna: protocol/decision No. 131, session held on May 11, 2023. All participants in the study have provided informed consent.

The study was conducted at the following location: University Dental Medical Center at the Medical University of Varna

The study included a total of 38 individuals (16 males and 22 females) with an average age of 29.8 years (ranging from 18 to 75 years).

Inclusion criteria for participants:

- signed informed consent;
- age over 18 years;
- gender: no preference;
- individuals without active orthodontic treatment;
- individuals with up to one missing tooth in the position of the first molars;
- individuals with up to one prosthetic restoration (crown) in the position of the first molars on a natural tooth;
- individuals with the presence of first premolars and central incisors in the lower jaw;
- good oral hygiene;
- individuals in overall good health.

Exclusion criteria for participants:

- individuals with severe systemic diseases;
- pregnancy and breastfeeding;
- age under 18 years;
- mental health disorders;
- individuals with missing first premolars and central incisors in the lower jaw;
- individuals with prosthetic restorations (crowns) in the position of first premolars and central incisors on natural teeth;
- individuals with restorations on implants in the lower jaw;
- acute and chronic inflammatory processes involving the hard and soft tissues in the oral cavity in the examination area;
- individuals with advanced periodontitis;
- individuals currently undergoing radiation therapy or chemotherapy.

METHODS

A preliminary clinical examination was conducted on each patient in order to analyze the existing dentition (in the lower jaw) and to assess eligibility for participation in the study based on the inclusion/exclusion criteria set.

Following the initial examination, for each of the approved participants, appointments were scheduled for clinical procedures and imaging studies, conducted in the following sequence:

1. placement of composite markers/buttons;
2. physical measurements;
3. intraoral scanning;
4. CBCT;
5. taking conventional impressions:
   a) taking an impression with A-silicone;
   b) taking an impression with polyether;
6. removing composite markers.

1. Placement of Composite Markers/Buttons

Before conducting intraoral measurements, composite markers were placed on the vestibular surfaces of teeth 36, 46, 34, and 44 to serve as reference points for individual measurements. A two-step etch-and-rinse protocol was used. The vestibular surface of the specified teeth was selectively etched in the area around the equator for 20 seconds, rinsed with water for at least 10 seconds, air-dried until a chalky white surface was visualized, and then a single-component adhesive, Universal Viva Pen, was applied for 10 seconds, followed by drying for 10 seconds and curing with a photopolymerization lamp (3M Elipar Deep Cure, 3M ESPE) for 20 seconds. Dual-cure composite material, Grandio Core Dual Cure (VOCO GmbH), was immediately applied after curing the bond, and the composite was cured for 20 seconds following its application.

2. Physical Measurements

After creating the composite markers, direct physical measurements were taken intraorally using a digital caliper, Kinex (Kinex measuring, Czech Republic), with a range of 0–300 mm, a jaw length of 60 mm, and a resolution of 0.01 mm. Linear distances in the lower jaw were measured between teeth 36 and 46, 34 and 44, 36 and 34, 46 and 44, 34—the midline between 31 and 41, and 44—the midline between 31 and 41. These values served as reference values for comparison. Measurements were recorded in millimeters with a tenth of a millimeter precision. The caliper was zeroed and calibrated before each subsequent measurement. When measuring distances between 34—midline between 31 and 41, and 44—midline 31 and 41, one end of the jaws was placed on a point between the central incisors in the middle third of the respective teeth.

3. Intraoral Scanning

Intraoral scanning was performed using Trios 4 (3Shape, Denmark, Copenhagen) following calibration before each new scan, in accordance with the scanning strategy for the lower jaw recommended by the manufacturer. The resulting model was exported and saved as an .STL file.

4. CBCT

Each volunteer in the study was scanned using a cone-beam computed tomograph, New Tom Giano HR Professional (2019), with the following parameters: tube voltage 90V, current 4mA, exposure time 8s, and a CMOS detector—a flat panel of amorphous silicon transforming X-ray energy into a digital signal. Prior to the imaging, informed consent for the imaging study was obtained. For image reconstruction, isotropic voxels with a size of 0.15 mm (150 microns) were used. The selected field of view (FOV) was 10x10. During scanning, the X-ray tube and detector rotated 360 degrees around the patient's head. Using an HP Z240 Tower Workstation with an Intel Xeon CPU E3-1270 v5, 3.60 GHz, 8.00 GB RAM, Windows 10 Pro, and NNT Viewer software, the obtained image was reconstructed in multi-planar reconstruction (MPR) mode in three planes.

5. Taking Conventional Impressions

a) Taking an Impression with A-Silicone

We used Medesy (Italy) metal trays. Each tray was coated with Universal Tray Adhesive (Zhermarck) and allowed to dry for 10 minutes before taking the impression. We used Elite HD+ Putty Soft Normal set (Zhermarck) in combination with Elite HD+ Light Body Normal Set (Zhermarck) (a one-step two-phase technique). Elite HD+ Putty Soft was mixed in equal amounts, both for the base and catalyst, measured using measuring spoons. Mixing was performed for 45–60 seconds in accordance with the manufacturer's recommendations, using latex-free gloves to reduce the risk of inhibiting the silicone polymerization process. The mixed putty material was then applied to the selected tray. The light body material was mixed using a dispensing gun and mixing cannulas in a 1:1 ratio and applied onto the putty material before placing the tray in the patient's mouth. After polymerization of the impression material, the tray was removed from the patient's mouth, rinsed with running water, and disinfected.

b) Taking an Impression with Polyether

We used standard Rim-Lock metal trays with pre-applied Polyether Adhesive (3M ESPE), which was applied 10 minutes before taking the impression and allowed to dry thoroughly. The polyether impression material we used was Impregum Monophase (3M ESPE), which was mixed using a Pentamix 3 (3M ESPE) machine for automatic mixing. After polymerization of the impression material, the tray was removed from the patient's mouth, rinsed with running water, and disinfected.

6. Removing Composite Markers

After performing physical measurements, taking digital and conventional impressions, and conducting CBCT, we removed the composite markers placed on the vestibular surfaces of the lower first molars and first premolars. We used a white Arkansas stone with a flame-shaped tip for a high-speed handpiece at 10,000 rotations per minute with water cooling for this purpose.

Subsequent laboratory and measurement steps include:

7. pouring gypsum models;
8. measurements on gypsum models;
9. converting DICOM to STL files from CBCT scans;
10. performing measurements on digital models from CBCT and intraoral scanning.

7. Pouring Gypsum Models

We poured the gypsum models within 12 hours after taking the conventional impressions. We used class 4 hard gypsum with Fuji rock EP Premium Line Pastel Yellow, following the manufacturer's recommended water-to-gypsum ratio. Mixing was performed using a vacuum gypsum mixer Renfert Twister venturi for one minute at a speed of 450 rpm, reaching 100% vacuum. The gypsum was then poured into the impressions placed on a Vibrax 230V/50Hz Renfert vibrating table at intensity level 3 and a low-frequency working module until maximum gypsum flow within the impression was achieved. Subsequently, the mixed gypsum was poured into a rubber mold for models and the impression tray with the impression material was placed on the mold. The setting time for this plaster is between 9 and 12 minutes, but the models were released from the impressions 24 hours after casting.

8. Measurements on Gypsum Models

After the gypsum models had set and been removed from the impressions, measurements were taken using a digital caliper, Kinex (Kinex measuring, Czech Republic), with a range of 0–300 mm, jaw length of 60 mm, and a resolution of 0.01 mm. Linear distances on the lower jaw were measured between teeth 36 and 46, 34 and 44, 36 and 34, 46 and 44, 34—the midline between 31 and 41, and 44—the midline between 31 and 41. The measurements were recorded in millimeters with a precision of one-tenth of a millimeter.

9. Converting DICOM to STL Files from CBCT Scans

We converted the generated DICOM files from CBCT scans into STL files to perform linear measurements using suitable software. The conversion was done using InVesalius 3.1 software, with the original resolution set to 100%. The conversion process included:

- manually setting a threshold value for tissue visualization, ranging from 1600 to 7500, to reduce artifact presence in the resulting 3D model while improving the visibility of composite markers;
- cropping unnecessary parts of the file volume using the Tools→Mask→Crop option;
- applying the Create Surface command with the following parameters: *method*: context-aware smoothing, *angle*: 0.7, *max. distance*: – 1.20, *min. weight*: 0.5, *n. steps*: 10;
- exporting and saving the resulting digital model as an STL file.

10. Performing Measurements on Digital Models from Intraoral Scanning and CBCT

To conduct measurements on digital models obtained from intraoral scanning and CBCT, we used 3Shape 3D Viewer. Since the software allows simultaneous measurement of up to three linear distances, the following approach was developed to optimize accuracy when measuring distances between teeth 36 and 46, 34 and 44, 36 and 34, 46 and 44, 34—the midline between 31 and 41, and 44—the midline between 31 and 41:

1. placing a digital marker on the midline between teeth 31 and 41;
2. placing a digital marker above the composite marker on the vestibular surface of tooth 34;
3. placing a digital marker above the composite marker on the vestibular surface of tooth 36 and positioning a second marker over the first marker on the vestibular surface of tooth 34, ensuring the markers align as accurately as possible;
4. placing a digital marker above the composite marker on the vestibular surface of tooth 44 and positioning a second marker over the marker on the vestibular surface of tooth 34, aiming for maximum alignment accuracy;
5. moving the first marker from the vestibular surface of tooth 34 onto the marker on the vestibular surface of tooth 44;
6. moving the second marker from the vestibular surface of tooth 34 onto the vestibular surface of tooth 46 above the composite marker;
7. moving a marker from the midline between teeth 31 and 41 onto the marker on the vestibular surface of tooth 46, ensuring maximum alignment accuracy between the markers.

In this way, distances were measured in the following order:

1. 34—the midline between 31 and 41;
2. 34–36;
3. 34–44;
4. 44—the midline between 31 and 41;
5. 36–46;
6. 44–46.

For each intraoral scan and 3D model from CBCT, measurements were conducted in this sequence to reduce the possibility of placing markers in different positions each time.

RESULTS

From all 38 participants in the study, the following measurements were taken:

- a total of 223 physical measurements;
- 223 primary and 126 repeat measurements on digital models obtained from intraoral scanning with a 3Shape Trios 4 IOS;
- 217 primary and 126 repeat measurements on 3D models generated from CBCT scans;
- 223 primary and 126 repeat measurements on gypsum models obtained from impressions with A-silicone (Elite HD+ Putty Soft Normal Set, Zhermarck) in combination with Elite HD + Light Body Normal Set (Zhermarck);
- 223 primary and 126 repeat measurements on gypsum models obtained from impressions with polyether (Impregum Soft, 3M ESPE).

The reason for the lower number of primary measurements on 3D models generated from CBCT scans compared to the others is due to image distortion in certain areas where there were strong radiopaque materials, making segmentation during conversion (from DICOM to STL files) almost impossible with the software used in this study.

The distribution of measurements based on the measured distances and modalities is presented in Fig 1.

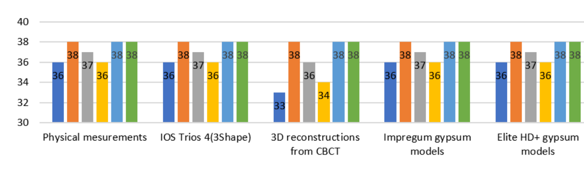

Fig. 1. Distribution of measurements based on the measured distances and modalities.

RELIABILITY

To assess the reliability of the investigated methodologies, we used the Pearson/Spearman correlation coefficient. Results from the reliability assessment of the researcher's measurements for the studied modalities indicate a correlation coefficient ranging from moderate to excellent with very high statistical significance. These results are presented in Table 1.

Regarding reliability, all tested modalities have proven to be reliable. However, there was a tendency to overestimate the measured lengths when conducting repeated measurements.

Table 1. Reliability assessment.

Linear Measurements	N	IOS		CBCT		Impregum		Elite HD+	
		r	p	r	p	r	p	r	p
46x36, mm	21	0.995**	<0.0001	0.977	<0.0001	0.981**	<0.0001	0.995**	<0.0001
44x34, mm	21	0.989**	<0.0001	0.983	<0.0001	0.991**	<0.0001	0.984**	<0.0001
36x34, mm	21	0.958**	<0.0001	0.803	<0.0001	0.834**	<0.0001	0.740**	<0.0001
46x44, mm	21	0.802**	<0.0001	0.848	<0.0001	0.850**	<0.0001	0.888**	<0.0001
34x31/41, mm	21	0.971**	<0.0001	0.969	<0.0001	0.965**	<0.0001	0.956**	<0.0001
44x31/41, mm	21	0.982**	<0.0001	0.980	<0.0001	0.967**	<0.0001	0.944**	<0.0001

ACCURACY

Concerning accuracy, differences were observed between individual modalities. Table 2 presents descriptive characteristics of the results obtained from measurements on the 3D reconstruction generated by CBCT and IOS, as well as on tooth reconstructions using gypsum models made from elastomeric impression materials (Impregum Monophase and Elite HD+).

Table 3 summarizes the results of the conducted analyses for the statistical hypothesis testing of the difference between means of two dependent samples (Paired t-test/Wilcoxon test) and the effect size (Effect Size) using Cohen's D.

RESULTS OF THE COMPARATIVE ANALYSIS BETWEEN THE INVESTIGATED MODALITIES

Results of the comparative analysis between the individual modalities for measuring linear distances between 46 and 36 are presented in Table 4.

There is no statistically significant difference between the individual modalities in measuring the linear distance between 46 and 36. Among the studied modalities, overestimation of measured values

Table 2. Accuracy between different modalitities.

Linear Measurements	Modalities	N	Mean	SD	SE	CI 95% for Mean		Min	Max
						Low	Up		
46x36, mm	Physical measurements	36	48.893	3.33	0.56	47.77	50.02	41.06	56.60
	IOS	36	48.960	3.40	0.57	47.81	50.11	40.52	56.61
	CBCT	33	49.015	3.37	0.59	47.82	50.21	41.62	56.50
	Impregum gypsum models	36	48.889	3.31	0.55	47.77	50.01	41.21	56.90
	Elite HD+ gypsum models	36	48.849	3.37	0.56	47.71	49.99	41.44	56.84
	Total	177	48.919	3.32	0.25	48.43	49.41	40.52	56.90
44x34, mm	Physical measurements	38	36.59	2.80	0.45	35.67	37.51	30.53	41.53
	IOS	38	36.45	2.88	0.47	35.51	37.40	29.75	41.39
	CBCT	38	36.44	2.79	0.45	35.52	37.36	30.21	41.53
	Impregum gypsum models	38	36.72	2.91	0.47	35.76	37.68	29.96	41.76
	Elite HD+ gypsum models	38	36.65	2.90	0.47	35.70	37.61	29.78	41.74
	Total	190	36.57	2.83	0.21	36.17	36.98	29.75	41.76

36x34, mm	Physical measurements	37	15.84	1.07	0.18	15.49	16.20	13.70	18.20
	IOS	37	16.02	1.01	0.17	15.68	16.35	14.33	17.99
	CBCT	36	16.11	1.06	0.18	15.76	16.47	13.97	18.15
	Impregum gypsum models	37	15.94	0.98	0.16	15.61	16.26	13.85	17.87
	Elite HD+ gypsum models	37	15.95	1.06	0.17	15.60	16.31	13.85	18.19
	Total	184	15.97	1.03	0.08	15.82	16.12	13.70	18.20
46x44, mm	Physical measurements	36	15.41	2.29	0.38	14.63	16.18	8.47	20.39
	IOS	36	15.64	2.46	0.41	14.81	16.47	8.15	20.94
	CBCT	34	15.61	2.51	0.43	14.74	16.49	8.24	20.91
	Impregum gypsum models	36	15.42	2.34	0.39	14.62	16.21	8.49	20.72
	Elite HD+ gypsum models	36	15.41	2.34	0.39	14.62	16.20	8.50	20.19
	Total	178	15.50	2.36	0.18	15.15	15.85	8.15	20.94
34x31/41, mm	Physical measurements	38	20.49	1.53	0.25	19.99	20.99	16.84	23.62
	IOS	38	20.73	1.59	0.26	20.21	21.25	17.58	24.12
	CBCT	38	20.70	1.56	0.25	20.18	21.21	17.60	24.79
	Impregum gypsum models	38	20.48	1.61	0.26	19.95	21.01	16.60	24.70
	Elite HD+ gypsum models	38	20.49	1.64	0.27	19.95	21.03	16.52	24.31
	Total	190	20.58	1.57	0.11	20.35	20.80	16.52	24.79
44x31/41, mm	Physical measurements	38	20.69	1.57	0.26	20.17	21.21	17.35	24.16
	IOS	38	21.04	1.56	0.25	20.53	21.56	18.06	24.52
	CBCT	38	21.13	1.58	0.26	20.61	21.65	17.97	24.52
	Impregum gypsum models	38	20.71	1.63	0.26	20.17	21.24	17.81	24.50
	Elite HD+ gypsum models	38	20.75	1.64	0.27	20.21	21.29	17.96	24.56
	Total	190	20.86	1.59	0.12	20.64	21.09	17.35	24.56

is observed in the group of 3D models from CBCT compared to the others.

Results of the comparative analysis between the individual modalities for measuring linear distances between 44 and 34 are presented in Table 5.

From the conducted statistical analysis for the linear distance between 44 and 34, it was found that there was a statistically significant difference in the mean difference values between the groups of IOS-Impregum, CBCT-Impregum, and CBCT-EliteHD. The mean difference values from measurements on elastomeric impression materials tend to be overestimated compared to the 3D models generated from CBCT. The same was observed for elastomers compared to IOS.

Results of the comparative analysis between the individual modalities for measuring linear distances between 36 and 34 are presented in Table 6.

Table 3. Summarized result from statistical hypothesis.

Statistical Hypothesis and Effect Size for Dependent Samples		Control & IOS 3 Shape	Control & 3D Reconstruction from CBCT	Control & Impregum	Control & Elite HD
46x36	Statistical significance	insignificant	insignificant	insignificant	insignificant
	Effect size	small	small	very small	very small
44x34	Statistical significance	insignificant	significant	insignificant	insignificant
	Effect size	small	small	small	very small
36x34	Statistical significance	insignificant	significant	insignificant	insignificant
	Effect size	small	moderate	small	small
46x44	Statistical significance	significant	significant	insignificant	insignificant
	Effect size	small	moderate	very small	very small
34x31/41	Statistical significance	significant	significant	insignificant	insignificant
	Effect size	moderate	moderate	very small	very small
44x31/41	Statistical significance	significant	significant	insignificant	insignificant
	Effect size	large	large	very small	very small

Table 4. Comparative analysis between the individual modalities for measuring linear distances between 46 and 36.

Modality comparison	Mean Dif	SE for Mean Dif	P*	CI 95% for Mean Dif.*	
				Low	Up
46x36, mm_IOS vs. 46x36, mm_CBCT	-0.059	0.095	1.000	-0.347	0.229
46x36, mm_IOS vs. 46x36, mm_Impregum	0.036	0.077	1.000	-0.196	0.268
46x36, mm_IOS vs. 46x36, mm_EliteHD	0.106	0.075	1.000	-0.120	0.333
46x36, mm_CBCT vs. 46x36, mm_Impregum	0.095	0.071	1.000	-0.120	0.310
46x36, mm_CBCT vs. 46x36, mm_EliteHD	0.165	0.064	0.149	-0.028	0.359
46x36, mm_Impregum vs. 46x36, mm_EliteHD	0.071	0.043	1.000	-0.059	0.201
* Bonferoni correction					

Table 5. Comparative analysis between the individual modalities for measuring linear distances between 44 and 34.

Modality Comparison	Mean Dif Low	SE for Mean Dif Up	P*	CI 95% for Mean Dif.*	
				Low	Up
44x34, mm_IOS vs. 44x34, mm_CBCT	0.010	0.059	1.000	-0.165	0.185
44x34, mm_IOS vs. 44x34, mm_Impregum	-.270*	0.073	0.007	-0.487	-0.053
44x34, mm_IOS vs. 44x34, mm_EliteHD	-0.201	0.077	0.137	-0.432	0.031
44x34, mm_CBCT vs. 44x34, mm_Impregum	-.280*	0.054	0.000	-0.443	-0.118
44x34, mm_CBCT vs. 44x34, mm_EliteHD	-.211*	0.061	0.013	-0.391	-0.030
44x34, mm_Impregum vs. 44x34, mm_EliteHD	0.070	0.042	1.000	-0.055	0.194
* Bonferoni correction					

Table 6. Comparative analysis between the individual modalities for measuring linear distances between 36 and 34.

Modality Comparison	Mean Dif	SE for Mean Dif	P*	CI 95% for Mean Dif.*	
				Low	Up
36x34, mm_IOS vs. 36x34, mm_CBCT	-0.105	0.055	0.659	-0.270	0.061
36x34, mm_IOS vs. 36x34, mm_Impregum	0.079	0.070	1.000	-0.130	0.289
36x34, mm_IOS vs. 36x34, mm_EliteHD	0.067	0.072	1.000	-0.149	0.283
36x34, mm_CBCT vs. 36x34, mm_Impregum	0.184	0.062	0.055	-0.002	0.371
36x34, mm_CBCT vs. 36x34, mm_EliteHD	0.171*	0.053	0.026	0.013	0.330
36x34, mm_Impregum vs. 36x34, mm_EliteHD	-0.013	0.043	1.000	-0.143	0.117
* Bonferoni correction					

Table 7. Comparative analysis between the individual modalities for measuring linear distances between 46 and 44.

Modality Comparison	Mean Dif	SE for Mean Dif	P*	CI 95% for Mean Dif.*	
				Low	Up
46x44, mm_IOS vs. 46x44, mm_CBCT	0.004	0.069	1.000	-0.205	0.213
46x44, mm_IOS vs. 46x44, mm_Impregum	0.185	0.086	0.393	-0.074	0.444
46x44, mm_IOS vs. 46x44, mm_EliteHD	0.181	0.078	0.265	-0.053	0.414
46x44, mm_CBCT vs. 46x44, mm_Impregum	0.181	0.071	0.156	-0.032	0.394
46x44, mm_CBCT vs. 46x44, mm_EliteHD	0.176	0.060	0.060	-0.004	0.357
46x44, mm_Impregum vs. 46x44, mm_EliteHD	-0.004	0.051	1.000	-0.158	0.150
* Bonferoni correction					

From the conducted statistical analysis for the linear distance between 36 and 34, it was found that there was a statistically significant difference in the mean difference values between the group of 3D models from CBCT and EliteHD, with a tendency to underestimate the obtained values for the elastomeric impression material compared to CBCT. There was no statistically significant difference observed between the measured mean difference values for the other modalities.

Results of the comparative analysis between the individual modalities for measuring linear distances between 46 and 44 are presented in Table 7.

There was no statistically significant difference in the mean difference values for measurements of the fourth quadrant between the examined modalities.

Results of the comparative analysis between the individual modalities for measuring linear distances between 34 and 31/41 are presented in Table 8.

Table 8. Comparative analysis between the individual modalities for measuring linear distances between 34 and 31/41.

Modality Comparison	Mean Dif	SE for Mean Dif	P*	CI 95% for Mean Dif.*	
				Low	Up
34x31_41, mm_IOS vs. 34x31_41, mm_CBCT	0.036	0.049	1.000	-0.111	0.182
34x31_41, mm_IOS vs. 34x31_41, mm_Impregum	0.255*	0.062	0.002	0.070	0.441
34x31_41, mm_IOS vs. 34x31_41, mm_EliteHD	0.244*	0.058	0.002	0.071	0.418
34x31_41, mm_CBCT vs. 34x31_41, mm_Impregum	0.219*	0.058	0.006	0.046	0.393
34x31_41, mm_CBCT vs. 34x31_41, mm_EliteHD	0.209*	0.058	0.010	0.035	0.383
34x31_41, mm_Impregum vs. 34x31_41, mm_EliteHD	-0.011	0.043	1.000	-0.138	0.116
* Bonferoni correction					

A statistically significant difference was observed between the elastomer groups (Impregum and Elite HD) and IOS and 3D CBCT model groups, with a tendency to underestimate the mean difference values for the elastomers compared to the other two groups.

Results of the comparative analysis between the individual modalities for measuring linear distances between 44 and 31/41 are presented in Table 9.

Table 9. Comparative analysis between the individual modalities for measuring linear distances between 44 and 31/41.

Modality Comparison	Mean Dif	SE for Mean Dif	P*	CI 95% for Mean Dif.*	
				Low	Up
34x31_41, mm_IOS vs. 34x31_41, mm_CBCT	-0.084	0.062	1.000	-0.270	0.102
34x31_41, mm_IOS vs. 34x31_41, mm_Impregum	0.335*	0.066	0.000	0.139	0.531
34x31_41, mm_IOS vs. 34x31_41, mm_EliteHD	0.292*	0.070	0.002	0.083	0.501
34x31_41, mm_CBCT vs. 34x31_41, mm_Impregum	0.419*	0.073	0.000	0.201	0.638
34x31_41, mm_CBCT vs. 34x31_41, mm_EliteHD	0.376*	0.071	0.000	0.165	0.588
34x31_41, mm_Impregum vs. 34x31_41, mm_EliteHD	-0.043	0.039	1.000	-0.158	0.073
* Bonferoni correction					

A statistically significant difference was observed between the elastomer groups (Impregum and Elite HD) and IOS and 3D CBCT model groups, with a tendency to underestimate the mean difference values for the elastomers compared to the other two groups.

DISCUSSION

At present, in the literature, we do not find data from in vivo studies conducted in the manner we selected—physical measurements intraorally from the lower jaw, which serve as controls. Devan Naidu and colleagues compared the accuracy of IOS to measurements with a digital caliper, but on gypsum models created from previously taken alginate impressions (6). The inconvenience of collecting patient data through physical measurements is the inability to repeat the measurements at any time. The placement of buttons is a factor that can influence subsequent measurements, as it is difficult to control their exact positioning and size. This, in turn, can affect measurements with the caliper since we placed the jaws of the caliper precisely over the buttons during measurements. Composite buttons are also registered during intraoral scanning, scanning with CBCT, and in elastomeric impressions, and their role is the same—to serve as reference points for measurements on the obtained reconstructions of the lower jaw, which we compare to physical measurements. To minimize the risk of composite buttons detaching, we used etch and bond before placing the composite on the buccal surfaces of the teeth.

In the study we conducted, each participant represented a separate experimental setup. For each participant, the physical measurements (intraorally taken with a digital caliper with an accuracy of up to one-tenth of a millimeter) served as controls compared to measurements on reconstructions from the examined modalities. Even the process of working with a digital caliper can influence the measured values, regardless of its sample device. Another important aspect that can have an impact, especially concerning measurements in the distal zones of the oral cavity, is the degree of mouth opening. Patients who can open wide find it much easier to measure interdental distances between the first molars in the third and fourth quadrants. The most challenging to register for all patients were the distances between the sixth and fourth teeth in the third and fourth quadrants due to the size of the caliper we used. A caliper with shorter jaws would be inconvenient for measuring in the distal areas.

In our study, we used the same CBCT machine for all participants and applied the same scanning parameters. Subsequently, the obtained DICOM files were converted into STL format using specialized software to perform similar linear measurements on the generated 3D reconstructions of the lower jaw.

One of the main sources of difficulty in visualizing images obtained through CBCT scanners is the formation of artifacts of various origins (7). Beam hardening is a phenomenon that causes deformations in the images around highly radiopaque materials (metals, zirconium, and composites).

For certain participants in the study (those with zirconium crowns on lower sixth teeth—two of them on tooth 46 and one on tooth 36), it was impossible to perform linear measurements because the model in these areas had significant deformations. Thus, the generated reconstructions were primarily applicable to patients without existing prosthetic restorations (on natural teeth or implants).

It is important to note that the head's position, when stable, does not directly impact the accuracy of the scanned object, as demonstrated in the literature (8,9). Despite this, great care was taken to ensure that all patients were as centered as possible during scanning.

According to some researchers, the voxel size does not significantly affect the accuracy and reliability of measurements on 3D models generated by CBCT (10,11). In our study, all scans were performed with isotropic voxels measuring 0.150 mm.

During scanning, we separated the patients' jaws using a plastic plate that was bitten with the cutting edges of the central incisors. This facilitated the visualization of interproximal areas (12). The volume of the scanning field was 10x10 since it is prescribed for medical reasons and requires the inclusion of the upper jaw, which was a limiting factor in our study. This may have an impact on the visibility of tooth surfaces and interproximal areas and affect the accuracy of measurements on 3D models. According to Bassan Hassan, there is a significant loss of quality in 3D models with a large scanning field. We cannot confirm this claim as we have not investigated the influence of this factor (12).

In the work of Marcelo Lupion Poleti and colleagues (13), an in vitro study was conducted to assess the reliability and accuracy of linear measurements on 3D models generated from CBCT using standard preset thresholds in two software programs for segmentation. The findings from this study showed that linear measurements on 3D models created from surfaces generated by standard preset thresholds in the Dolphin and InVesalius software are considered reliable and accurate when compared to physical measurements. In our study, we used InVesalius version 3.1 software to convert the DICOM files to an STL format, but we could not determine the specific influence of the software on the generated models. In our study, the models generated in this way were noted to be the least accurate compared to the studied models, although we did not find this to have clinical significance.

Most studies establish high accuracy in linear measurements conducted on 3D models generated by CBCT (12,14–19). These studies use dry skulls and jaws for their experiments, with some including the simulation of soft tissues around the scanned object. However, this type of experimental design cannot fully replicate the conditions in real patients. J.K. Dusseldorp et al. (20) have pointed out that the accuracy of segmenting 3D models of hard tissues in the craniofacial complex and the lower jaw, obtained from CBCT, may be affected by the presence of soft tissues, and their impact may be below the generally accepted level of clinical significance, around 1 mm. In our study, we focused on the accuracy of interdental distance measurements in the lower jaw, where precision requirements are not as high, but we still found statistically significant differences compared to the controls. Despite the statistically significant differences, the results in our study were still within the generally accepted level of clinical significance, around 1 mm. Our study provides valuable data regarding the reliability of 3D models generated by CBCT scanners using real patients. This represents a significant step forward in understanding the capabilities and limitations of these models in clinical applications. The fact that we used real patients contributes to the real-world reproduction of clinical scenarios and adds complexity to the study. Additionally, our efforts to standardize the measurement process among different models, as well as the use of the same software, contribute to minimizing the possible variations and errors related to the different steps of the study.

Danielle R. Periago et al. (21) found that most of the linear measurements in their study statistically differed from anatomical dimensions; however, most of them could be considered sufficiently accurate for clinical craniofacial analysis. This corresponds to the results of our study.

In CA Lascala et al.'s study (22) they found that the measured distances on CBCT files tended to underestimate the measurements made with a digital caliper on dry skulls, but they were still reliable for linear measurements to evaluate structures closely related to dentofacial imaging. Sebastian Baumgaertel et al. (14) found that dental measurements conducted on 3D reconstructions from CBCT can be used for quantitative analysis, as they prove to be highly reliable, even though there is a tendency for these measurements to slightly underestimate the anatomical truth. In our study, we observed a tendency to overestimate the measured distances, but we agree that 3D reconstructions from CBCT are suitable for conducting quantitative analyses.

In addition to accuracy, Mija Kim et al. (23) also assessed the reliability of measurements and found that values from repeat measurements exhibited excellent reliability with a high intraclass correlation coefficient, which corresponds to the results of our study. High intraclass correlation coefficients were also found by Thais Maria Freire Fernandes et al. (11) who cautioned that linear measurements on 3D images were reliable but not precise, which aligns with the results of our study.

Intraoral scanners have been the subject of research by numerous authorship teams (24–29) and appear to be a reliable alternative to conventional methods for creating non-removable constructions, both on natural teeth (30–33) and implants (34,35).

Every year, new IOS systems enter the market, making it challenging to study the accuracy and reliability of each one of them. There are numerous factors that can influence these parameters in different systems: the scanning process, the light source, the need for coating powder before scanning (36), the operational procedure, various contactless optical technologies (37), the type of the final file (38–40), and others. Some of these factors are beyond the control of dental practitioners as they are related to the manufacturing process and technologies of different scanners. On the other hand, as operators, we can control certain aspects during scanning that may affect the accuracy of the generated models.

One of the most recognizable IOSs is the 3Shape Trios. This system has been the subject of research in some studies conducted so far (41,42), but there is still a lack of studies entirely focused on the performance of a specific scanner under different clinical or laboratory conditions.

Most studies have been conducted under experimental settings (28,42–44) where factors related to working on patients, such as the possibility of movement during scanning, gag reflex, saliva, the presence of cheeks and tongue, and restrictions in mouth opening, were eliminated. This certainly has a positive impact on the accuracy of research results.

In our study, we used the Trios 4 IOS (3Shape) and scanned only the lower jaw of real patients while placing them in a stable position with the head stabilized on the dental chair headrest. This way, we generated a digital diagnostic model on which we conducted linear measurements resembling orthodontic analysis (6). One of our goals was to determine the accuracy of linear measurements made on reconstructions of the lower jaw from IOS compared to intraoral measurements with a digital caliper.

In clinical practice, there are numerous factors that can influence the accuracy of the created model. Gan Ning and his team demonstrated that even the width of the dental arch could affect scanning accuracy (45), but this is an aspect we cannot directly control. The bending of the lower jaw, known as mandibular flexure (46) can also affect the model's accuracy compared to the real clinical situation, but there is no objective way to determine the degree of this bending. Therefore, during scanning, we encouraged patients not to open their lower jaw too wide. Saliva is a factor that can affect the model's accuracy (47), so before each scan, we used a three-function spray handle to dry the area of the lower jaw and then used aspiration from the dental unit to remove saliva as best as possible.

Environmental factors like ambient light (48) and temperature (49) are also important considerations when it comes to their influence on the accuracy of IOS. Some studies recommend turning off the light in the dental unit to minimize unwanted effects (48). The same principles for optimal color capture are supported by the recommendations of 3Shape. In the context of our research, we conducted intraoral scans with the unit light turned off and maintained ambient temperature at levels around 22–24 degrees Celsius. The scanning strategy represents a factor that affects the accuracy of the digital impression and depends directly on the operator's actions (50). According to observations by A. Ender and A. Mehl (51), available intraoral scanning systems demonstrate high accuracy in generating impressions for the entire dental arch when suitable scanning strategies are employed. Priscilla Medina-Sotomayar and her team conducted studies on various scanning strategies for four IOSs and found that this aspect had a stronger impact on the accuracy and precision of scanning for some devices compared to others (52). Based on the findings of these studies, we decided to follow a scanning strategy for the lower jaw according to the manufacturer's recommendations.

Studies by Peter Rehmann and colleagues (53) emphasized that calibrating IOS before use had a positive impact on scanning accuracy. For this reason, we performed calibration before each scan.

According to the results of Ji-Won Anh's study (41) the alignment of teeth was not included as a determining factor in patient selection for the current study. Patients wearing braces (38) and implants (54) were excluded from the study, because the presence of such elements could impact scanning results and would definitely affect the scanning process with CBCT.

Based on our observations regarding comfort and speed, the IOS we used performed exceptionally well, consistent with conclusions from other studies (20,55,56). The average time required for scanning was approximately 1 minute, which was definitely shorter than the time needed for conventional impressions. We did not register any cases in which patients experienced a gag reflex. An additional advantage of working with the 3Shape Trios 4 was the ability to rescan specific areas if the results were unsatisfactory without the need for an entirely new scan. This provided convenience and saved time. Furthermore, we had the opportunity to immediately assess the quality of the generated model in its true colors, which is not possible with conventional impression methods.

To perform linear measurements on the created models, we used specialized software (3Shape 3D Viewer). To guide the placement of markers between specific points, we utilized pre-attached composite buttons on the vestibular surfaces of teeth 46, 36, 44, and 34. Ensuring the accuracy of measurements required precise positioning of digital markers. It was essential to follow a specific sequence when placing markers and measuring between points, as this stage carried the potential for error. The protocol we applied was tailored to the limitations of the software, which allowed us to perform up to three linear measurements simultaneously. The same software and protocol were used for measurements on 3D models generated through CBCT.

The limitations of measurements conducted in this manner were directly related to the limitations of the software used. One of the main challenges we encountered was the precise placement of more than one digital marker on the same point on the digital model's surface. This could potentially influence the measurements conducted.

Under these conditions, the models generated and the measurements conducted with IOS were satisfactory compared to the control measurements taken using a digital caliper directly in the mouths of the participants in this study. Similar conclusions were drawn in Devan Naidu's study, despite differences in the study design (6). According to Andreas Ender and colleagues (57), digital systems do not significantly differ in terms of accuracy when capturing the entire dental arch. However, high-precision conventional impression materials provide higher accuracy than digital methods, which corresponds to the results of our studies. Several studies (29,49,55) have found that intraoral scanning systems show similar accuracy to that of models obtained from polyvinyl siloxane and polyether impression materials for single teeth, and in some cases, even higher accuracy (58). Due to the limitations of our study, we cannot confirm or deny the claims made in these studies.

Ala Omar Ali conducted a study (59) comparing the accuracy of digital impressions obtained with different digital impression systems. They found that, for a situation involving a three-unit fixed prosthesis, some of the examined systems performed similarly to scans using conventional impression materials. However, other systems yielded less precise results than conventional methods. Andres Ender et al. conducted a clinical study and found that scanning a quadrant had a level of accuracy comparable to a model obtained from a conventional polyvinyl siloxane impression with a sectional tray (60). Conventional impression methods with a rigid full-arch tray demonstrated the highest accuracy compared to all tested digital systems. There are differences in precision among various digital systems, but all fall within the range where clinically satisfactory restorations can be created. In our study, we tested only one intraoral scanning system, but based on the results, we can confirm what Andres Ender established. A. Ender and A. Mehl compared conventional and digital impression methods for the entire dental arch. They reported similarity in accuracy and precision between polyether impressions and two IOSs (25). In another study (24), they concluded that the accuracy and precision of digital impressions for the entire arch were less precise than those of conventional impressions with polyvinyl siloxane, which aligns with the results of our study. Although the results of scanning with an IOS appear clinically satisfactory, we found higher accuracy in reconstructions from conventional impression materials.

Impression-taking is a routine procedure for dental practitioners, with elastomeric materials being among the most commonly used. One of the primary qualities of impression materials is their volumetric stability and accuracy, which depend on the degree of completion of the chemical reaction between the primary components and the type of polymerization reaction. Linear contraction in different types of elastomers primarily differs due to the formation of low-molecular-weight secondary products. According to literature data, the contraction for 24 hours in various types of elastomers is 0.10% for polyethers and is lowest for addition silicones at 0.05% (61). Volumetric stability of impression materials over time can be influenced by several factors: the completeness of the chemical reaction, the formation and evaporation of low-molecular-weight secondary products (such as water, alcohol, and hydrogen), water imbibition (when the material is not hydrophobic), stress relaxation due to specific form and processing conditions, and temperature variations between body temperature and room temperature, as well as the impression technique, type of impression tray used, and related factors (62).

For the purposes of the study, two impressions were taken from each participant using two different elastomeric impression materials: A-silicone (Elite HD+) and polyether (Impregum Monophase). In the case of A-silicone impressions, a one-step dual-mix technique was used, while for polyether impressions, a monophase technique was employed. This approach was chosen to optimize the conventional impression-taking process and reduce the potential accumulation of secondary deformations that may occur when using two-step methods, as mentioned in some scientific sources (61). Despite arguments presented by some authors (63) for higher accuracy of two-step methods, other studies (64,65) do not confirm significant differences between one-step and two-step techniques. Based on the results of our study, we believe that the one-step technique for taking impressions with A-silicone and monophase technique with polyether leads to the casting of accurate gypsum reconstructions of lower dental arch.

For A-silicone impressions, we used metal perforated trays to reduce the potential risk of deformation during impression-taking. This choice was made due to the high density of the paste, which could compress the surrounding tissues during impression-taking, as reported in the literature (61,66,67). In the case of polyether impressions, we opted for standard metal trays of the Rim-Lock type, as Impregum Monophase is characterized by lower viscosity and, consequently, a reduced risk of tissue compression. Before taking the impressions, the tray surfaces were treated with an adhesive, which was allowed to dry for a minimum of 10 minutes. According to T. J. Bomberg, this adhesive application process on the tray is a critical phase in the impression-taking procedure, contributing to more precise and consistent results (68).

The impression-taking procedure using both of the materials (A-silicone and polyether) under consideration required approximately 5 minutes for each material, which proved to be more time-consuming compared to the time needed for intraoral scanning.

When using analog impressions, there is a risk of deformation after processing with disinfectants (39,69). This is a mandatory step after removing the impression tray from the patient's mouth and rinsing it with running water to reduce the risk of spreading infection to the dental laboratory (70). Additionally, if optimal conditions are not maintained during transportation, analog impressions can be subject to deformations (61).

In comparison, IOSs are characterized by the absence of a risk of cross-contamination, as the transfer of information occurs digitally. Advantages also include easier communication with the laboratory, as the models can be reviewed immediately, whereas with conventional impressions, errors are often identified after the gypsum model has already been cast. The process of casting gypsum models is an additional step in conventional methods that can lead to the generation of hidden deformations.

A benefit of digital models is that they do not change during our work with them and do not require additional physical space, whereas gypsum models can break or get damaged during measurements on them, as well as during transportation, and they require storage space.

CONCLUSION

In summary, conventional methods and materials still outperform IOSs in terms of the accuracy of obtained reconstructions. 3D models generated from CBCT scans are generally the least satisfactory among the tested modalities, with deviations typically within clinically acceptable values (under 1 mm). While impression materials and IOSs do not pose a direct health risk to patients and demonstrate greater accuracy in terms of obtained models, CBCT involves X-ray exposure and requires additional processing of the generated files before they can be used for analysis.

Regarding accuracy, we can summarize the results as follows:

- most accurate method: Elite HD+;
- second most accurate method: Impregum;
- less accurate method: 3Shape Trios;
- least accurate method: 3D model generated from CBCT study.

Given the limitations of this study, we believe that additional research is needed to gather more data on the subject. Conventional methods and modern technologies do not exclude each other but complement each other, and we should strive to choose the best approach based on a given clinical situation.

REFERENCES

1. Brownstein, Sheri A.; Murad, Aseel; Hunt, Ronald J. Implementation of new technologies in U.S. dental school curricula. J Dent Educ. 2015;79(3):259–64. doi:10.1002/j.0022-0337.2015.79.3.tb05880.x.
2. Iacopino AM. The influence of "new science" on dental education: current concepts, trends, and models for the future. J Dent Educ. 2007;71(4):450-62.
3. Iliev G. The art and future of digital dentistry. J Med Dent Pract. 2021;8(1):1278-84. doi:10.18044/Medinform.202181.1278.
4. Macleod I, Heath N. Cone-beam computed tomography (CBCT) in dental practice. Dent Update. 2008;35(9):590–8. doi:10.12968/denu.2008.35.9.590
5. Schepke U, Meijer HJ, Kerdijk W, Cune MS. Digital versus analog complete-arch impressions for single-unit premolar implant crowns: Operating time and patient preference. J Prosthet Dent. 2015;114(3):403-6.e1. doi: 10.1016/j.prosdent.2015.04.003.
6. Naidu D, Freer TJ. Validity, reliability, and reproducibility of the iOC intraoral scanner: a comparison of tooth widths and Bolton ratios. Am J Orthod Dentofacial Orthop. 2013;144(2):304-10. doi: 10.1016/j.ajodo.2013.04.011.
7. Mallya SM, Lam E. White and Pharoah's oral radiology, principles and interpretation. 8th ed. Mosby; 2018.
8. Hassan B, van der Stelt P, Sanderink G. Accuracy of three-dimensional measurements obtained from cone beam computed tomography surface-rendered images for cephalometric analysis: influence of patient scanning position. Eur J Orthod. 2009;31(2):129-34. doi: 10.1093/ejo/cjn088.
9. Ludlow JB, Laster WS, See M, Bailey LJ, Hershey HG. Accuracy of measurements of mandibular anatomy in cone beam computed tomography images. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007;103(4):534-42. doi: 10.1016/j.tripleo.2006.04.008.
10. Damstra J, Fourie Z, Huddleston Slater JJ, Ren Y. Accuracy of linear measurements from cone-beam computed tomography-derived surface models of different voxel sizes. Am J Orthod Dentofacial

Orthop. 2010;137(1):16.e1-6; discussion 16-7. doi: 10.1016/j.ajodo.2009.06.016.

11. Fernandes TM, Adamczyk J, Poleti ML, Henriques JF, Friedland B, Garib DG. Comparison between 3D volumetric rendering and multiplanar slices on the reliability of linear measurements on CBCT images: an in vitro study. J Appl Oral Sci. 2015;23(1):56-63. doi: 10.1590/1678-775720130445.

12. Hassan B, Couto Souza P, Jacobs R, de Azambuja Berti S, van der Stelt P. Influence of scanning and reconstruction parameters on quality of three-dimensional surface models of the dental arches from cone beam computed tomography. Clin Oral Investig. 2010;14(3):303-10. doi: 10.1007/s00784-009-0291-3.

13. Poleti ML, Fernandes TM, Pagin O, Moretti MR, Rubira-Bullen IR. Analysis of linear measurements on 3D surface models using CBCT data segmentation obtained by automatic standard pre-set thresholds in two segmentation software programs: an in vitro study. Clin Oral Investig. 2016;20(1):179-85. doi: 10.1007/s00784-015-1485-5.

14. Baumgaertel S, Palomo JM, Palomo L, Hans MG. Reliability and accuracy of cone-beam computed tomography dental measurements. Am J Orthod Dentofacial Orthop. 2009;136(1):19-25; discussion 25-8. doi: 10.1016/j.ajodo.2007.09.016.

15. Benavides E, Rios HF, Ganz SD, An CH, Resnik R, Reardon GT, et al. Use of cone beam computed tomography in implant dentistry: the International Congress of Oral Implantologists consensus report. Implant Dent. 2012;21(2):78-86. doi: 10.1097/ID.0b013e31824885b5.

16. Cevidanes LH, Styner MA, Proffit WR. Image analysis and superimposition of 3-dimensional cone-beam computed tomography models. Am J Orthod Dentofacial Orthop. 2006;129(5):611-8. doi: 10.1016/j.ajodo.2005.12.008.

17. Kapila SD, Nervina JM. Cone-beam computed tomography in orthodontics: assessment of treatment outcomes and indications for its use. Dentomaxillofacial Radiology, 2015;44(1):20140282. doi: 10.1259/dmfr.20140282.

18. Lagravère MO, Carey J, Toogood RW, Major PW. Three-dimensional accuracy of measurements made with software on cone-beam computed tomography images. Am J Orthod Dentofacial Orthop. 2008 Jul;134(1):112-6. doi: 10.1016/j.ajodo.2006.08.024.

19. Liang X, Lambrichts I, Sun Y, Denis K, Hassan B, Li L, Pauwels R, Jacobs R. A comparative evaluation of cone beam computed tomography (CBCT) and multi-slice CT (MSCT). Part II: On 3D model accuracy. Eur J Radiol. 2010;75(2):270-4. doi: 10.1016/j.ejrad.2009.04.016.

20. Dusseldorp JK, Stamatakis HC, Ren Y. Soft tissue coverage on the segmentation accuracy of the 3D surface-rendered model from cone-beam CT. Clin Oral Investig. 2017;21(3):921-30. doi: 10.1007/s00784-016-1844-x.

21. Periago DR, Scarfe WC, Moshiri M, Scheetz JP, Silveira AM, Farman AG. Linear accuracy and reliability of cone beam CT derived 3-dimensional images constructed using an orthodontic volumetric rendering program. Angle Orthod. 2008;78(3):387-95. doi: 10.2319/122106-52.1.

22. Lascala CA, Panella J, Marques MM. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). Dentomaxillofac Radiol. 2004;33(5):291-4. doi: 10.1259/dmfr/25500850.

23. Kim M, Huh KH, Yi WJ, Heo MS, Lee SS, Choi SC. Evaluation of accuracy of 3D reconstruction images using multi-detector CT and cone-beam CT. Imaging Sci Dent. 2012;42(1):25-33. doi: 10.5624/isd.2012.42.1.25.

24. Ender A, Mehl A. Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. J Prosthet Dent. 2013;109(2):121-8. doi: 10.1016/S0022-3913(13)60028-1.

25. Ender A, Mehl A. Full arch scans: conventional versus digital impressions--an in-vitro study. Int J Comput Dent. 2011;14(1):11-21. English, German.

26. Flügge TV, Schlager S, Nelson K, Nahles S, Metzger MC. Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner. Am J Orthod Dentofacial Orthop. 2013;144(3):471-8. doi: 10.1016/j.ajodo.2013.04.017.

27. Rudolph H, Salmen H, Moldan M, Kuhn K, Sichwardt V, Wöstmann B, et al. Accuracy of intraoral and extraoral digital data acquisition for dental restorations. J Appl Oral Sci. 2016;24(1):85-94. doi: 10.1590/1678-775720150266.

28. Lee JJ, Jeong ID, Park JY, Jeon JH, Kim JH, Kim WC. Accuracy of single-abutment digital cast obtained using intraoral and cast scanners. J

Prosthet Dent. 2017;117(2):253-9. doi: 10.1016/j.prosdent.2016.07.021.

29. Yang X, Lv P, Liu Y, Si W, Feng H. Accuracy of digital impressions and fitness of single crowns based on digital impressions. Materials (Basel). 2015;8(7):3945-57. doi: 10.3390/ma8073945.

30. Almeida e Silva JS, Erdelt K, Edelhoff D, Araújo É, Stimmelmayr M, Vieira LC, Güth JF. Marginal and internal fit of four-unit zirconia fixed dental prostheses based on digital and conventional impression techniques. Clin Oral Investig. 2014;18(2):515-23. doi: 10.1007/s00784-013-0987-2.

31. Boeddinghaus M, Breloer ES, Rehmann P, Wöstmann B. Accuracy of single-tooth restorations based on intraoral digital and conventional impressions in patients. Clin Oral Investig. 2015;19(8):2027-34. doi: 10.1007/s00784-015-1430-7.

32. Dauti R, Cvikl B, Lilaj B, Heimel P, Moritz A, Schedle A. Micro-CT evaluation of marginal and internal fit of cemented polymer infiltrated ceramic network material crowns manufactured after conventional and digital impressions. J Prosthodont Res. 2019;63(1):40-46. doi: 10.1016/j.jpor.2018.04.005.

33. Svanborg P, Skjerven H, Carlsson P, Eliasson A, Karlsson S, Ortorp A. Marginal and internal fit of cobalt-chromium fixed dental prostheses generated from digital and conventional impressions. Int J Dent. 2014;2014:534382. doi: 10.1155/2014/534382.

34. Imburgia M, Logozzo S, Hauschild U, Veronesi G, Mangano C, Mangano FG. Accuracy of four intraoral scanners in oral implantology: a comparative in vitro study. BMC Oral Health. 2017;17(1):92. doi: 10.1186/s12903-017-0383-4.

35. Mangano FG, Hauschild U, Veronesi G, Imburgia M, Mangano C, Admakin O. Trueness and precision of 5 intraoral scanners in the impressions of single and multiple implants: a comparative in vitro study. BMC Oral Health. 2019;19(1):101. doi: 10.1186/s12903-019-0792-7.

36. Nedelcu RG, Persson AS. Scanning accuracy and precision in 4 intraoral scanners: an in vitro comparison based on 3-dimensional analysis. J Prosthet Dent. 2014;112(6):1461-71. doi: 10.1016/j.prosdent.2014.05.027.

37. Gogushev K, Abadzhiev M, Georgieva K, Denkov I. Intraoral scanning systems based on the principle of confocal microscopy used in modern prosthetic dental medicine. Varna Med Forum. 2017;6(1):80-5. doi:10.14748/vmf.v6i1.1925.

38. Song J, Kim M. Accuracy on scanned images of full arch models with orthodontic brackets by various intraoral scanners in the presence of artificial saliva. Biomed Res Int. 2020;2020:2920804. doi: 10.1155/2020/2920804.

39. Sree lakshmi SB, Somasundram J, Geetha RV. Disinfection of impression material – a review. Eur J Mol Clin Med. 2020;7(1):978-85.

40. Ting-Shu S, Jian S. Intraoral Digital Impression Technique: A Review. J Prosthodont. 2015;24(4):313-21. doi: 10.1111/jopr.12218.

41. Anh JW, Park JM, Chun YS, Kim M, Kim M. A comparison of the precision of three-dimensional images acquired by 2 digital intraoral scanners: effects of tooth irregularity and scanning direction. Korean J Orthod. 2016;46(1):3-12. doi:10.4041/kjod.2016.46.1.3.

42. Uhm SH, Kim JH, Jiang HB, Woo CW, Chang M, Kim KN, et al. Evaluation of the accuracy and precision of four intraoral scanners with 70% reduced inlay and four-unit bridge models of international standard. Dent Mater J. 2017;36(1):27-34. doi: 10.4012/dmj.2016-064.

43. . Güth JF, Runkel C, Beuer F, Stimmelmayr M, Edelhoff D, Keul C. Accuracy of five intraoral scanners compared to indirect digitalization. Clin Oral Investig. 2017;21(5):1445-55. doi: 10.1007/s00784-016-1902-4.

44. Kim JE, Amelya A, Shin Y, Shim JS. Accuracy of intraoral digital impressions using an artificial landmark. J Prosthet Dent. 2017;117(6):755-61. doi: 10.1016/j.prosdent.2016.09.016.

45. Gan N, Xiong Y, Jiao T. Accuracy of intraoral digital impressions for whole upper jaws, including full dentitions and palatal soft tissues. PLoS One. 2016;11(7):e0158800. doi: 10.1371/journal.pone.0158800.

46. Mijiritsky E, Shacham M, Meilik Y, Dekel-Steinkeller M. Clinical influence of mandibular flexure on oral rehabilitation: narrative review. Int J Environ Res Public Health. 2022;19(24):16748. doi: 10.3390/ijerph192416748.

47. Chen Y, Zhai Z, Li H, Yamada S, Matsuoka T, Ono S, et al. Influence of liquid on the tooth surface on the accuracy of intraoral scanners: an in vitro study. J Prosthodont. 2022;31(1):59-64. doi: 10.1111/jopr.13358.

48. Revilla-León M, Subramanian SG, Att W, Krishnamurthy VR. Analysis of different illuminance of the room lighting condition on the accuracy (trueness and precision) of an intraoral scanner. J Prosthodont. 2021;30(2):157-62. doi: 10.1111/jopr.13276.

49. Revilla-León M, Gohil A, Barmak AB, Gómez-Polo M, Pérez-Barquero JA, Att W, et al. Influence of ambient temperature changes on intraoral scanning accuracy. J Prosthet Dent. 2022:S0022-3913(22)00061-0. doi: 10.1016/j.prosdent.2022.01.012.

50. Müller P, Ender A, Joda T, Katsoulis J. Impact of digital intraoral scan strategies on the impression accuracy using the TRIOS Pod scanner. Quintessence Int. 2016;47(4):343-9. doi: 10.3290/j.qi.a35524.

51. Ender A, Mehl A. Influence of scanning strategies on the accuracy of digital intraoral scanning systems. Int J Comput Dent. 2013;16(1):11-21. English, German.

52. Medina-Sotomayor P, Pascual-Moscardó A, Camps I. Accuracy of four digital scanners according to scanning strategy in complete-arch impressions. PLoS One. 2018;13(9):e0202916. doi: 10.1371/journal.pone.0202916.

53. Rehmann P, sichwardt v, wöstmann b. intraoral scanning Systems: Need for Maintenance. Int J Prosthodont. 2017;30(1):27-29. doi: 10.11607/ijp.4976.

54. Chew AA, Esguerra RJ, Teoh KH, Wong KM, Ng SD, Tan KB. Three-dimensional accuracy of digital implant impressions: effects of different scanners and implant level. Int J Oral Maxillofac Implants. 2017;32(1):70-80. doi: 10.11607/jomi.4942.

55. Lee SJ, Gallucci GO. Digital vs. conventional implant impressions: efficiency outcomes. Clin Oral Implants Res. 2013;24(1):111-5. doi: 10.1111/j.1600-0501.2012.02430.x.

56. Park HR, Park JM, Chun YS, Lee KN, Kim M. Changes in views on digital intraoral scanners among dental hygienists after training in digital impression taking. BMC Oral Health. 2015;15(1):151. doi: 10.1186/s12903-015-0140-5.

57. Ender A, Attin T, Mehl A. In vivo precision of conventional and digital methods of obtaining complete-arch dental impressions. J Prosthet Dent. 2016;115(3):313-20. doi: 10.1016/j.prosdent.2015.09.011.

58. Carbajal Mejía JB, Wakabayashi K, Nakamura T, Yatani H. Influence of abutment tooth geometry on the accuracy of conventional and digital methods of obtaining dental impressions. J Prosthet Dent. 2017;118(3):392-9. doi: 10.1016/j.prosdent.2016.10.021.

59. Ali AO. Accuracy of digital impressions achieved from five different digital impression systems. Dent. 2015;5(5):1-6. doi:10.4172/2161-1122.1000300.

60. Ender A, Zimmermann M, Attin T, Mehl A. In vivo precision of conventional and digital methods for obtaining quadrant dental impressions. Clin Oral Investig. 2016;20(7):1495-504. doi: 10.1007/s00784-015-1641-y.

61. Kisov H. Impression materials and impression techniques. Index;1998.

62. Gonçalves FS, Popoff DA, Castro CD, Silva GC, Magalhães CS, Moreira AN. Dimensional stability of elastomeric impression materials: a critical review of the literature. Eur J Prosthodont Restor Dent. 2011;19(4):163-6.

63. Dugal R, Railkar B, Musani S. Comparative evaluation of dimensional accuracy of different polyvinyl siloxane putty-wash impression techniques-in vitro study. J Int Oral Health. 2013;5(5):85-94.

64. Hung SH, Purk JH, Tira DE, Eick JD. Accuracy of one-step versus two-step putty wash addition silicone impression technique. J Prosthet Dent. 1992;67(5):583-9. doi: 10.1016/0022-3913(92)90151-y.

65. Idris B, Houston F, Claffey N. Comparison of the dimensional accuracy of one- and two-step techniques with the use of putty/wash addition silicone impression materials. J Prosthet Dent. 1995;74(5):535-41. doi: 10.1016/s0022-3913(05)80358-0.

66. Rueda LJ, Sy-Muñoz JT, Naylor WP, Goodacre CJ, Swartz ML. The effect of using custom or stock trays on the accuracy of gypsum casts. Int J Prosthodont. 1996;9(4):367-73.

67. Valderhaug J, Fløystrand F. Dimensional stability of elastomeric impression materials in custom-made and stock trays. J Prosthet Dent. 1984;52(4):514-7. doi: 10.1016/0022-3913(84)90336-6.

68. Bomberg TJ, Goldfogel MH, Hoffman W Jr, Bomberg SE. Considerations for adhesion of impression materials to impression trays. J Prosthet Dent. 1988;60(6):681-4. doi: 10.1016/0022-3913(88)90398-8.

69. Thouati A, Deveaux E, Iost A, Behin P. Dimensional stability of seven elastomeric impression materials immersed in disinfectants. J Prosthet Dent. 1996;76(1):8-14. doi: 10.1016/s0022-3913(96)90338-8.

70. Georgescu CE, Skaug N, Patrascu I. Cross infection in dentistry. Rom Biotechnol Lett. 2002;7:861-8.