Validation of model analysis according to the severity of crowding of digital models obtained by intraoral and model scanners

Jaehee Yoon

The Graduate School
Yonsei University
Department of Dentistry

Validation of model analysis according to the severity of crowding of digital models obtained by intraoral and model scanners

A Master's Thesis
Submitted to the Department of Dentistry
and the Graduate School of Yonsei University
in partial fulfillment of the requirements for the degree of
Master of Dental Science

Jae hee Yoon

June 2016

This certifies that the master's thesis of Jae hee Yoon is approved

Cha J. Y

Thesis Supervisor: Jung-Yul Cha

H. S. Yu

Prof. Hyung-Seog Yu

Yoonchoi

Prof. Yoon-Jeong Choi

The Graduate School

Yonsei University

June 2016

Table of contents

List of Figures

List of Tables

ABSTRACT

Validation of model analysis according to the severity of crowding of digital models obtained by intraoral and model scanners

Jae hee Yoon, D.D.S.

Department of Dentistry

The graduate school, Yonsei University

(Directed by Prof. Jung-Yul Cha, D.D.S., M.S., PhD)

In this study, the correspondence between linear measurements taken from cast models, cast-scan models, and intraoral-scan models in patients who had various degrees of tooth crowding was assessed. Fifty-eight patients who had undergone both intraoral scans for diagnosis and for whom cast models were made for indirect bonding were included. Cast models were divided into two groups depending on the amount of crowding, as determined by initial caliper-based measurements. Cast models with crowding of less than 3.0 mm were included in the mild crowding (MC) group, and those with crowding of more than 4.5 mm were included in the moderate to severe crowding (SC) group. Twenty maxillary models and 20 mandibular models were randomly chosen from each of the groups and digital scans were

performed. For the three types of models, i.e., intraoral scan digital model (IS), cast model (C), and cast-scan digital model (CS), linear measurement was performed twice by one graduate student. First, the reproducibility of the repeated linear measurements from each model was estimated. The mean values of repeated linear measurements from each model were compared to evaluate the precision of the measurements. We found that linear measurements made using digital calipers on a cast model and on the relevant software were reproducible. The mean differences ranged from -0.01 mm to 0.12 mm on the mesio-distal width of teeth, -0.30 mm to 0.45 mm in the arch width, and 0.14 to 1.35 mm in the arch length. In the MC group, there was a significant difference in the amount of crowding between cast and intraoral scans of the maxilla (mean difference: 0.78 mm; $p < 0.05$). In the SC group, there was a significant difference in the amount of crowding on both the maxilla and the mandible between the cast and intraoral scans (mean difference: 0.86 mm and 0.51 mm, respectively; $p < 0.05$). There was no interaction between the amount of crowding and the precision of the linear measurements in the three models ($p > 0.05$). Thus, there was no significant difference in most linear measurements between digital models and the cast model. There were significant differences in crowding, although these were not clinically meaningful, and there was no relationship to the severity of crowding. Thus, as with cast models, digital models can also be used for measuring crowding for orthodontic diagnoses in both patients with mild and those with severe crowding. However, the tendency for detection of less crowding in digital models should be considered.

Key words: cast model, crowding, digital model, intraoral scan, linear measurement, space analysis

Validation of model analysis according to the severity of crowding of digital models obtained by intraoral and model scanners

Jae hee Yoon, D.D.S.

Department of Dentistry

The graduate school, Yonsei University

(Directed by Prof. Jung-Yul Cha, D.D.S., M.S., PhD)

Ⅰ. Introduction

Digital orthodontic cast-scan models were introduced for commercial use by Orthocad (Cadent, Carlstadt, NJ, USA) in 1999. The benefits of this digital model include instant access to three-dimensional (3D) information, the ability to perform accurate and simple diagnostic set-ups of various extraction patterns, easy transfer across platforms for instant referral or consultation, and objective model-grading analysis (Fleming et al., 2011). The accuracy of dental model analysis is essential for application of digital models for diagnostic purposes (Han et al., 1991). Recently, greater accuracy has been required for digital models, as 3D models are used not only for diagnosis, but also as models for setting up treatment and for the fabrication of orthodontic appliances (Reuschl et al., 2015).

Many studies have assessed the accuracy of digital models in making orthodontic diagnoses and linear measurements (Goonewardene et al., 2008; Horton et al., 2010; Keating et al., 2008; Leifert et al., 2009; Mullen et al., 2007; Quimby et al., 2004; Santoro et al., 2003; Stevens et al., 2006). Simple linear measurements made on digital models match those made on conventional cast models, such as intermolar and intercanine width (Horton et al., 2010; Leifert et al., 2009), mesio-distal width of the tooth (Stevens et al., 2006), height of the tooth (Keating et al., 2008), and overjet and overbite (Leifert et al., 2009; Mullen et al., 2007; Quimby et al., 2004). However, there were significant differences between digital and conventional models in terms of other diagnostic values, such as the Bolton ratio, space analysis, and irregularity ratio (Leifert et al., 2009; Stevens et al., 2006; Tomassetti et al., 2001).

Leifert et al. (2009) evaluated the precision of space analysis with digital models fabricated using alginate impressions and Orthocad software and that of cast models in patients with 2–7-mm crowding. The difference in the amount of crowding between the digital and the cast models was less than 0.5 mm. Because the image view is 2D, despite making use of a 3D model, it is difficult to establish points, axes, inclinations, and planes, which may decrease the validity of such measurements. Despite these errors, those authors concluded that the measurements are reproducible and clinically acceptable compared to conventional model analysis, and could be used in making orthodontic diagnosis.

Redlich and colleagues (Redlich et al., 2008) performed space analysis on both cast models and digital models obtained by scanning cast models using a model scanner. The author reported that there was no significant difference in the width of any tooth. In terms of the total amount of crowding, however, the difference between cast and digital model was 1.19–3

mm. The authors speculated that the discrepancy in crowding between the cast model and digital model was significantly increased by accumulation of errors during the process of measuring the extent of crowding. The study concluded that space analysis in the cast-scan model differed less from that in the conventional cast models in patients with mild crowding, but that it may not be appropriate to use digital models in a clinical situation in patients with severe crowding. Correia and colleagues (2014) also reported that there was no significant difference when comparing crowding in a cast model with that in a cast-scan model, and compared crowding measured using available arch length determined as the sum of sectional arch lengths. However, the subjects were limited to those with mild crowding, with a low median value of crowding of -0.41 mm.

It is now possible to obtain intraoral digital scans directly due to the development of the intraoral scanner (Kurbad, 2011; Stein, 2011). Even though intraoral scanners have been commonly used in the past few years, the accuracy of the intraoral scanner needs to be evaluated, as most accuracy assessments have been limited to single elements, such as crowns, inlays, or bridges (Brawek et al., 2013; da Costa et al., 2010; Luthardt et al., 2005; Syrek et al., 2010). Some studies have also evaluated the scanning time and the accuracy of orthodontic diagnosis made using intraoral scans (Del Corso et al., 2009; Luthardt et al., 2003; Rudolph et al., 2007).

Grunheid et al. (2014) suggested that there was no significant difference between cast-scan models and intraoral-scan models when they were digitally superimposed and the surface areas compared. Wiranto et al. (2013) compared the mesio-distal width of teeth using the Bolton ratio of intraoral-scan models, cast models (which act as the gold standard), and cone-beam computed tomography scans of cast models in patients who had mild to moderate crowding. There was no significant difference in the mesio-distal width of teeth in these

comparisons. However, there was a significant difference in the Bolton ratio, which was too small to be clinically relevant. Therefore, the authors suggested that tooth size measurement and the Bolton ratio of digital models could be used in patients with mild to moderate crowding, even though the study did not include patients with severe crowding.

Recently, some studies have used reference models to assess the accuracy of intraoral scanning to evaluate the precision and trueness of the total arch scan model (Ender and Mehl, 2013; Patzelt et al., 2014). They concluded that it produced clinically acceptable results. However, intraoral scan models taken from real patients might be less accurate, due to patient movement, limited intraoral space, intraoral humidity, and saliva flow (Flugge et al., 2013). Further studies are needed to validate the accuracy of intraoral scanning in real patients.

Given this background, it is clear that further studies are needed to assess the use of intraoral scanned digital models for complex diagnostic cast analyses, such as crowding, particularly in real patients with severe crowding. The purpose of this study was to assess the relationship between the accuracy of linear measurement and crowding by comparing intraoral-scan models, cast-scan models, and cast models of patients with various degrees of crowding.

Ⅱ. Materials and methods

1. Sample

Approval for this study was obtained from the institutional review board of the Yonsei University. One-hundred-and-forty-three sets of maxillary and mandibular pretreatment intraoral-scan impressions of patients who visited the orthodontic clinic at the College of Dentistry at Yonsei University in Seoul, Korea, from December 2013 to April 2016 were used for this study. Inclusion criteria were as follows:

1) Absence of dentofacial deformity or medical problems.
2) Absence of previous orthodontic history with fixed appliances.
3) Eruption of all permanent teeth, without any impacted, missing, or super-numerary teeth, from one first molar to the next first molar.
4) Availability of an intraoral-cast model and a cast model.

In total, 46 patients were included in this study

Linear measurements of overjet and overbite were performed for the 46 patients. To highlight the contrast in severity, samples were divided into two groups, depending on the amount of crowding determined by initial caliper-based measurements. Cast models in cases where the amount of crowding was less than 3.0 mm were included in the mild crowding (MC) group (maxilla [Mx.]: n = 20, mandible [Mn.]: n = 20), and those with more than 4.5 mm were included in the moderate to severe crowding (SC) group (Mx.: n = 20, Mn. n = 20). Linear measurements of arch width, arch length, tooth width, sectional arch length were performed in the 80 arches.

2. Methods

1) Model manipulation

It is ethically and clinically not possible to obtain linear measurements of the width of actual patients' teeth (Stevens et al., 2006); therefore, cast models and two types of digital models were analyzed and compared in this study. Intraoral-scan (IS) models were obtained for diagnosis using an intraoral scanner (TRIOS 3; 3Shape, Copenhagen, Denmark). Alginate (Cavex CA37; CAVEX, Haarlem, Holland) impressions were taken from patients who were scheduled for treatment with indirect bonding. All of the alginate impressions were confirmed immediately and, where necessary, impressions were retaken until the quality was acceptable for making a diagnosis. Wax bite registration was taken with centric occlusion in an upright position.

Cast models (C) were made in the standard way using pouring plaster (Rhombstone White; Ryoka Dental, Mie-Ken, Japan). All cast models were scanned using the Orapix 3D dental system (Orapix, Seoul, Korea), yielding the cast-scan model (CS).

2) Scanning method

Intraoral scanning was performed according to the manufacturer's (TRIOS 3; 3Shape, Copenhagen, Denmark) protocol. All patients were seated upright and with adequate moisture control in their mouth.

Arch scan: Scanning started with the most-distal tooth of one side; the scanner was slowly wiggled when passing the central teeth. Lingual scanning was performed with lingual tilting at an angle of 45–90º to the occlusal plane, and the tongue was retracted by the tip of the intraoral scanner.

Bite scan: The scanner tip was posed at the buccal side of the 2nd molar with patients biting with centric occlusion. Bite scanning was performed with the scan image centered on the occlusal plane, and the scanner tip was slowly moved in the mesial direction, covering the upper and lower teeth equally.

All digital models were 3D orientated and model data saved in stereolithographic (STL) files.

3) Measuring methods

Linear measurements of cast models were performed using a digital caliper (Fisher Scientific International Inc., Hampton, NH, USA), which had an accuracy of 1/100 mm. Linear values of digital models were measured with a Rapidform XOR3 64 (Geomagic, Morrisville, NC, USA) and saved to an accuracy of 1/100 mm. All of the linear measurements were performed twice by one operator (Y.J.H), with an interval of more than 1 week between assessments.

Linear measurements are defined below in Table 1.

Table 1. Linear measurements used in this study

Site	Definition
M6	The widest width of first molar at occlusal view
M5	The widest width of second premolar at occlusal view
M4	The widest width of first premolar at occlusal view
M3	The widest width of canine at labial view
M2	The widest width of lateral incisor at labial view
M1	The widest width of central incisor at labial view
PSL	Length between mesial contact point of first molar and distal contact point of canine (Posterior segment length)
ASL	Length between distal contact point of canine and mesial contact point of both central incisors (Anterior segment length)
OB	Distance of the lowest point of upper central incisors and the highest point of opposite tooth
OJ	Distance of the most anterior point of upper central incisors and the most anterior point of opposite tooth
AWC	Distance between cusp tips of both canines (Arch width of canine)
AWM	Distance between central fossae of both first molars (Arch width of molar)
AL	Distance from the line connecting the distal surface of the first molars to the contact point between the central incisors (Arch length)

Tooth width was measured at the greatest width in an occlusal view for posterior teeth and in the labial view in anterior teeth. Before the measurement, it was confirmed that the line between two measuring points was parallel to the central groove and perpendicular to the axis of the tooth when measuring posterior teeth. It was ascertained that the line between two measuring points was perpendicular to the axis and that both measuring points were in the middle of the labio-lingual distance on the incisal view. If this was not the case, the measurement was repeated.

Sectional arch length was measured in the following manner. The available arch length (AL) was separated into four segments, from the mesial region of the first molar to the mesial surface of the first premolar and from the mesial region of the first premolar to contact point of central teeth, on both the left and right sides. When measuring the posterior sectional arch length, the most-buccal point of the contact surface of the canine and first premolar was chosen as measuring point.

AL was defined as the distance perpendicular from the line connecting the distal surface of the first molars to the contact point between the central incisors.

Arch width was defined as the distance between the central fossae of both the first molars (6 to 6, AWM) and between the tips of the cusp of the canines (3 to 3, AWC).

Overjet (OJ) was defined as the distance of the most anterior point of the maxillary central incisors and the most anterior point of opposite tooth.

Overbite (OB) was defined as the distance between the lowest point of the maxillary central incisors and the highest point of the opposite tooth.

Crowding (Cr.) was defined as follows: (the sum of the mesio-distal width of the 2nd premolar to the opposite 2nd premolar) - (the sum of the sectional arch length).

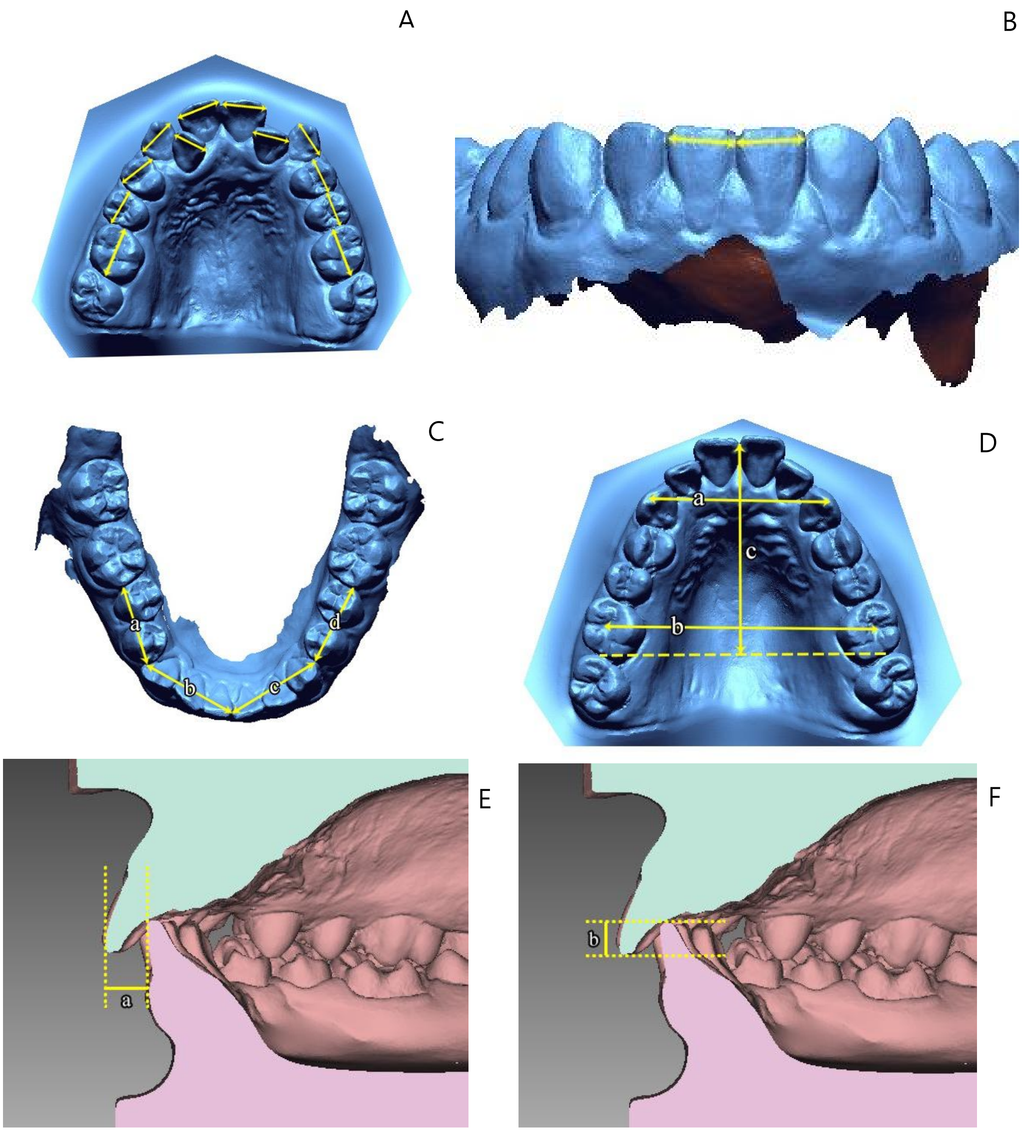

Figure 1 .Linear measurements used in this study

A and B. Tooth width measurement: The greatest width of the posterior tooth in the occlusal view, the greatest width of the anterior tooth in the labial view.

C. Sectional arch length was measured in four separate segments.

a,d Posterior sectional arch length: Length between the mesial contact point of the first molar and the distal contact point of the canine.

b,c Anterior sectional arch length: Length between the distal contact point of the canine and the mesial contact point of both central incisors

D. a,b Arch width: The distance between the cusp tips of both canines and both first molars.
c Arch length: The distance from the line connecting the distal surface of the first molars to the contact point between the central incisors.
E. a Overjet
F. b Overbite

3. Statistical analysis

Intraclass correlation coefficients (ICCs) were calculated to confirm reproducibility. After confirming reproducibility, the mean values of two measurements taken on both the maxilla and the mandible were calculated and were compared for each linear measurement of one cast model and two digital models, using repeated-measurements ANOVA (Bonferroni's method). Samples were divided into the MC group and the SC group, depending on the severity of crowding; the precision of three linear measurements and the amount of crowding in the three kinds of models were compared by repeated-measures ANOVA. Finally, the difference in the precision of measurement in each model between the MC and SC groups was confirmed using the Greenhouse–Geisser correction. All statistical analyses were performed using SPSS (version 21; SPSS, Chicago, IL, USA).

Ⅲ. Results

1. Distribution of crowding

The amount of crowding in the two groups is shown in Table 2.

Table 2. Crowding of mild and severe crowding groups of cast model, cast-scan model and intra oral scan model groups for maxillary and mandibular dentition (mm)

Groups	Maxilla			Mandible		
	Mean	SD	Range	Mean	SD	Range
MC group						
Cast model	1.23	1.48	-1.98~2.99	1.47	1.04	-1.24~2.78
Cast scan model	1.16	1.58	-2.19~2.91	1.10	0.94	-0.64~3.04
Intraoral scan model	0.52	1.41	-2.68~3.18	0.92	1.01	-0.99~2.70
SC group						
Cast model	6.57	2.13	4.34~12.33	6.68	3.01	4.19~14.34
Cast scan model	5.99	1.95	3.76~11.98	6.06	3.16	3.68~13.46
Intraoral scan model	5.71	2.23	3.97~11.23	6.17	2.96	3.60~13.27
						(n=80)

MC group: mild crowding group, SC group: severe crowding group

2. Reproducibility of measurements

The intraclass correlation values of the two measurements ranged from 0.96 to 1.00 (Table 3); thus, the measurements were highly reproducible.

Table 3. Reproducibility of measurement values with ICC values based on absolute agreement

Measure -ment	Cast(C)		Cast scan(CS)		Intraoral scan(IS)	
	ICC	95% CI	ICC	95% CI	ICC	95% CI
M1	1.00	1.00-1.00	1.00	1.00-1.00	1.00	0.99-1.00
M2	0.99	0.99-0.99	0.99	0.99-0.99	0.97	0.96-0.98
M3	0.99	0.99-0.99	0.99	0.99-0.99	0.98	0.98-0.99
M4	0.99	0.98-0.99	0.99	0.98-9.99	0.97	0.96-0.98
M5	0.99	0.98-0.99	0.98	0.98-0.99	0.97	0.96-0.98
M6	0.98	0.98-0.99	0.99	0.99-0.99	1.00	0.98-0.99
PSL	0.99	0.99-1.00	1.00	0.99-1.00	0.99	0.99-0.99
ASL	1.00	1.00-1.00	1.00	1.00-1.00	1.00	1.00-1.00
OJ	1.00	1.00-1.00	1.00	1.00-1.00	0.99	0.99-1.00
OB	1.00	1.00-1.00	1.00	1.00-1.00	0.99	0.99-1.00
AWC	1.00	1.00-1.00	1.00	1.00-1.00	1.00	1.00-1.00
AWM	1.00	1.00-1.00	1.00	1.00-1.00	1.00	1.00-1.00
AL	1.00	1.00-1.00	0.99	0.99-1.00	1.00	0.99-1.00

CI, Confidence interval
(M1~M6: n=160, P,A,AWC, AWM, AL: n=80 OJ,OB: n=46)

PSL: posterior segmental arch length, ASL: anterior segmental arch length, OJ: overjet, OB: overbite AWC, inter canine width, AWM: inter molar width, AL: Arch length

3. Comparison of linear measurements between the three models

1) Comparison of mean Overjet and Overbite of cast model and 2 digital models

There was no significant difference in the values of overjet and overbite between the three models (Table 4).

Table 4. Mean overjet and overbite of cast model and 2 digital models (mm)

Measure -ment	Cast (Mean±SD)	Cast scan (Mean±SD)	Intraoral scan (Mean±SD)	Mean deviation/ Standard error (*p*)	
Over -bite	0.73 ±2.11	0.74 ±2.01	0.77 ±2.06	C-CS	-.01/.33 (1.00)
				C-IS	-.04/.09 (1.00)
				CS-IS	-.04/.33 (1.00)
Overjet	2.69 ±2.87	2.59 ±2.75	2.62 ±2.79	C-CS	.11/.38 (1.00)
				C-IS	.07/.08 (1.00)
				CS-IS	-.04/.36 (1.00)
	Performed RM-ANOVA,			(n=46)	

2) Comparison of mean linear measurements of a cast model and 2 digital models of the maxilla

The mean values of linear measurements of each of the 40 cast models, cast-scan models, and intraoral-scan models of the maxilla are compared in Table 5. There was no significant difference between cast and cast-scan models, or between cast-scan and intraoral-scan models. However, there were some significant differences between the cast and intraoral-scan models, specifically in the mesio-distal width of the lateral incisor (p = .01), 1st premolar (p = .00), 2nd premolar (p = .00), 1st molar (p = .00), and AL (p = .00).

Table 5. Mean linear measurements of cast model and 2 digital models in maxillary dentition (mm)

	Cast (Mean±SD)	Cast scan (Mean±SD)	Intraoral scan (Mean±SD)	Mean difference/ Standard error (p)	
M1	8.68±0.55	8.68±0.55	8.65±0.57	C-CS	.00/.04 (1.00)
				C-IS	.03/.05 (.16)
				CS-IS	.03/.05 (1.00)
M2	7.39±0.56	7.31±0.55	7.32±0.53	C-CS	.07/.06 (.57)
				C-IS	.07/.03 (.03)*
				CS-IS	.00/.06 (1.00)
M3	8.16±0.43	8.16±0.42	8.15±0.44	C-CS	-.00/.05 (1.00)
				C-IS	.00/.02 (1.00)
				CS-IS	.01/.05 (1.00)
M4	7.76±0.48	7.74±0.47	7.64±0.50	C-CS	.03/.06 (1.00)
				C-IS	.12/.02 (.00)**
				CS-IS	.10/.06 (.32)
M5	7.26±0.50	7.22±0.50	7.15±0.49	C-CS	.04/.06 (1.00)
				C-IS	.10/.03 (.00)**
				CS-IS	.06/.06 (.89)
M6	10.61±0.64	10.54±0.65	10.53±0.63	C-CS	.06/.07 (1.00)
				C-IS	.08/.03 (.03)**
				CS-IS	.01/.08 (1.00)
PSL	15.52±2.65	15.53±2.65	15.42±2.48	C-CS	-.01/.12 (1.00)
				C-IS	.10/.11 (1.00)
				CS-IS	.10/.17 (1.00)
ASL	21.76±2.78	21.80±2.79	21.91±2.69	C-CS	-.04/.19 (1.00)
				C-IS	-.15/.12 (.71)
				CS-IS	-.11/.22 (1.00)
AWC	35.25±2.46	35.20±2.56	34.99±2.41	C-CS	.22/.39 (1.00)
				C-IS	.14/.09 (.45)
				CS-IS	-.08/.39 (1.00)
AWM	48.98±3.75	48.84±3.56	48.88±3.90	C-CS	-.08/.43 (1.00)
				C-IS	-.13/.15 (1.00)
				CS-IS	-.06/.42 (1.00)

AL	**40.87±2.88**	**40.44±2.81**	**39.28±2.58**	**C-CS**	**.26/.53 (1.00)**
				C-IS	**1.35/.30 (.00)****
				CS-IS	**1.09/.66 (.23)**

Performed RM ANOVA, *: p<0.05, **: p<0.005
(M1~M6: n=80,   P,A,AWC, AWM, AL: n=40)

PSL: posterior segmental arch length, ASL: anterior segmental arch length, OJ: overjet, OB: overbite AWC, inter canine width, AWM: inter molar width, AL: Arch length

3) Comparison of mean linear measurements of a cast model and 2 digital models of the mandible

The mean values of the linear measurements of the 40 cast models, cast-scan models, and intraoral-scan models of the mandible were also compared (Table 6). There were significant differences between the cast and intraoral-scan models in the mesio-distal width of the 1st and 2nd premolars (both p = .00). Moreover, there was a significant difference between the cast and cast-scan models in terms of the mesio-distal width of the 1st premolar(p=.00). The mean value for tooth width from the cast models were larger than those obtained from the digital models (0.01–0.12 mm). There were also significant differences in the arch width at the molars and arch length between cast and intraoral-scan models.

Table 6. Mean linear measurements of cast model and 2 digital models in mandibular dentition. (mm)

	Cast (Mean±SD)	Cast scan (Mean±SD)	Intraoral scan (Mean±SD)	Mean difference/ Standard error(*p*)	
M1	5.67±0.39	5.65±0.37	5.67±0.37	C-CS	.02/.03(1.00)
				C-IS	.00/.02(1.00)
				CS-IS	-.01/.03(1.00)
M2	6.34±0.42	6.32±0.40	6.29±0.45	C-CS	.02/.04(1.00)
				C-IS	.04/.02(.11)
				CS-IS	.03/.04(1.00)
M3	7.18±0.43	7.16±0.43	7.17±0.45	C-CS	.02/.03(1.00)
				C-IS	.01/.02(1.00)
				CS-IS	-.01/.03(1.00)
M4	7.65±0.47	7.56±0.46	7.54±0.49	C-CS	.08/.03(.05)*
				C-IS	.11/.02(.00)**
				CS-IS	.02/.04(1.00)
M5	7.58±0.50	7.50±0.51	7.45±0.54	C-CS	.08/.05(.38)
				C-IS	.12/.02(.00)*
				CS-IS	.05/.05(1.00)
M6	11.58±0.59	11.51±0.61	11.51±0.62	C-CS	.07/.06(.66)
				C-IS	.07/.03(.05)
				CS-IS	.00/.06(1.00)
PSL	15.02±1.01	15.01±1.02	14.98±1.05	C-CS	.01/.08(1.00)
				C-IS	.04/.03(.47)
				CS-IS	.03/.08(1.00)
ASL	17.36±1.64	17.40±1.65	17.37±1.67	C-CS	-.05/.13(1.00)
				C-IS	-.01/.03(1.00)
				CS-IS	.04/.13(1.00)
AWC	27.23±2.86	27.20±2.86	27.10±2.84	C-CS	.03/.41(1.00)
				C-IS	.13/.06(.10)
				CS-IS	.10/.42(1.00)
AWM	42.58±3.11	42.13±3.53	42.43±3.22	C-CS	.45/.55(1.00)
				C-IS	.15/.06(.03)*
				CS-IS	-.30/.55(1.00)

AL	**36.36±2.46**	**36.33±2.53**	**35.51±2.14**	**C-CS**	**.14/.50(1.00)**
				C-IS	**.95/.26(.00)****
				CS-IS	**.81/.51(.35)**

Performed RM ANOVA, *: p<0.05, **: p<0.005
(M1~M6: n=80, P,A,AWC, AWM, AL: n=40)

PSL: posterior segmental arch length, ASL: anterior segmental arch length, OJ: overjet, OB: overbite AWC, inter canine width, AWM: inter molar width, AL: Arch length

4. Comparative analysis of mean values of linear measurements and crowding between groups

1) Comparison of linear measurements between groups in maxilla dentition

The comparison of the maxillary linear measurements in the three models in the MC and SC groups is shown in Table 7. There were significant differences in the mesio-distal widths of the maxillary 1st premolar (p = .00) and 2nd premolar (p = .01), and in the amount of crowding (p = .01) between the cast and intraoral scans in the MC group. There was also a significant difference in the mesio-distal width of 1st premolar (p = .01) between the cast-scan and intraoral-scans. In the SC group, there was a significant difference between the cast and intraoral scans at the maxillary lateral incisor (p = .00) and 1st premolar (p = .01), and in the amount of crowding (p = .02).

Table 7. Comparison of linear measurements between 2 groups in maxillary dentition (mm)

	Cast (Mean±SD)		Cast scan (Mean±SD)		Intraoral scan (Mean±SD)		Mean difference (p)		
	MC	SC	MC	SC	MC	SC		MC	SC
M1	8.50 ±0.46	8.87 ±0.57	8.54 ±0.49	8.82 ±0.57	8.48 ±0.47	8.82 ±0.61	C-CS	-.04(.59)	-.04(1.00)
							C-IS	.02(1.00)	.05(.12)
							CS-IS	.06(.31)	.01(1.00)
M2	7.16 ±0.55	7.62 ±0.47	7.12 ±0.55	7.51 ±0.49	7.17 ±0.54	7.47 ±0.49	C-CS	.05(.26)	.10(1.00)
							C-IS	-.00(1.00)	.15(.00)**
							CS-IS	-.05(.36)	.05(1.00)
M3	8.10 ±0.38	8.21 ±0.46	8.12 ±0.39	8.20 ±0.45	8.08 ±0.42	8.22 ±0.45	C-CS	-.02(1.00)	.01(1.00)
							C-IS	.02(1.00)	-.01(1.00)
							CS-IS	.38(.44)	-.02(1.00)
M4	7.66 ±0.42	7.87 ±0.52	7.64 ±0.39	7.84 ±0.52	7.51 ±0.43	7.78 ±0.53	C-CS	.02(1.00)	.03(1.00)
							C-IS	.15(.00)**	.09(.01)*
							CS-IS	.13(.01)*	.06(1.00)
M5	7.15 ±0.48	7.36 ±0.50	7.11 ±0.49	7.32 ±0.50	7.02 ±0.45	7.29 ±0.50	C-CS	.04(.82)	.04(1.00)
							C-IS	.14(.00)**	.07(.29)
							CS-IS	.09(.06)	.04(1.00)
M6	10.40 ±0.59	10.81 ±0.63	10.34 ±0.61	10.74 ±0.65	10.33 ±0.50	10.73 ±0.68	C-CS	.06(.23)	.07(1.00)
							C-IS	.07(.15)	.08(.25)
							CS-IS	.15(1.00)	.01(1.00)
Cr	1.30 ±1.48	6.57 ±2.13	1.16 ±1.58	5.99 ±1.95	0.52 ±1.41	5.72 ±2.23	C-CS	-.02(1.00)	.58(1.00)
							C-IS	.78(.01)**	.86(.02)*
							CS-IS	.64(.07)	-.27(1.00)

Performed RM ANOVA, Cr: crowding,*: $p<0.05$,**: $p<0.005$
(M1~M6: n=40, P,A,AWC, AWM, AL, Cr: n=20)
MC: mild group (crowding<3mm), SC: severe group (crowding>4.5mm)

2) Comparison of linear measurements between groups in mandibular dentition

The results of comparing mandibular linear measurements in the three models between the MC and SC groups are shown in Table 8. There were significant differences in the mesio-distal width of the mandibular 1st premolar (*p* = .02), 2nd premolar (*p* = .01), and 1st molar (*p* = .00) between the cast and cast-scan models in the MC group. Furthermore, there were also significant differences in the mesio-distal width of the mandibular 1st premolar (*p* = .00), 2nd premolar (*p* = .00), and 1st molar (*p* = .00) between the cast and intraoral-scan models in the MC group. In the SC group, there were significant differences between the cast and intraoral scans in the mesio-distal width of the mandibular 1st premolar (*p* = .00) and 2nd premolar (*p* = .00), and in the amount of crowding (*p* = .02). Only the mandibular 2nd premolar (*p* = .00) in the MC group showed significant differences in width between the cast-scan and intraoral-scan models.

Table 8. Comparison of linear measurements between 2 groups in mandibular dentition(mm)

MC: mild group (crowding<3mm), SC: severe group (crowding>4.5mm)

	Cast (Mean±SD)		Cast scan (Mean±SD)		Intraoral scan (Mean±SD)		Mean difference (*p*)		
	MC	SC	MC	SC	MC	SC		MC	SC
M1	5.62 ±0.40	5.72 ±0.39	5.63 ±0.36	5.67 ±0.37	5.64 ±0.38	5.69 ±0.37	C-CS	-.01(1.00)	.04(1.00)
							C-IS	-.02(.1.00)	.03(.62)
							CS-IS	-.01(1.00)	-.01(1.00)
M2	6.30 ±0.44	6.38 ±0.41	6.38 ±0.46	6.37 ±0.34	6.24 ±0.49	6.35 ±0.41	C-CS	-.02(1.00)	.01(1.00)
							C-IS	.06(.35)	.03(.46)
							CS-IS	.04(.99)	.02(1.00)
M3	7.13 ±0.46	7.23 ±0.40	7.10 ±0.47	7.23 ±0.40	7.10 ±0.47	7.23 ±0.42	C-CS	.03(0.48)	.01(1.00)
							C-IS	.02(1.00)	.01(1.00)
							CS-IS	-.00(1.00)	-.01(1.00)
M4	7.53 ±0.44	7.76 ±0.47	7.47 ±0.45	7.66 ±0.46	7.42 ±0.48	7.66 ±0.47	C-CS	.06(.02)*	.11(.33)
							C-IS	.12(.00)**	.10(.01)*
							CS-IS	.05(.42)	-.00(1.00)
M5	7.52 ±0.52	7.63 ±0.49	7.43 ±0.55	7.56 ±0.46	7.33 ±0.57	7.57 ±0.48	C-CS	.09(.01)*	.07(1.00)
							C-IS	.19(.00)**	.06(.00)**
							CS-IS	.10(.03)**	-.01(1.00)
M6	11.59 ±0.57	11.57 ±0.62	11.49 ±0.58	11.55 ±0.65	11.49 ±0.60	11.53 ±0.65	C-CS	.11(.00)**	.03(1.00)
							C-IS	.10(.00)*	.04(1.00)
							CS-IS	-.01(1.00)	.01(1.00)
Cr	1.47 ±1.04	6.68 ±3.00	1.10 ±0.94	6.06 ±3.16	0.92 ±1.01	6.18 ±2.96	C-CS	.37(.10)	.63(1.00)
							C-IS	.55(.06)	.51(.02)*
							CS-IS	.18(1.00)	-.12(1.00)

Performed RM ANOVA, Cr: crowding,*: $p<0.05$,**: $p<0.005$
(M1~M6: n=40, P,A,AWC, AWM, AL,C†: n=20)

5. Interaction effect

1) Effect of severity of crowding on dental measurements in the three dental models

The effect of the severity of crowding on the dental measurements in the three dental models was confirmed by using repeated-measures ANOVA (Table 9), but there were no statistically significant differences between models. There was no interaction between severe crowding (more than 4.5 mm) and the precision of dental measurements in the three dental models.

Table 9. Effect of severity of crowding on the dental measurements in the three dental models

Mx.	*p*	Mn.	*P*
M1	0.49	M1	0.51
M2	0.27	M2	0.85
M3	0.66	M3	0.85
M4	0.64	M4	0.59
M5	0.70	M5	0.27
M6	0.96	M6	0.62
PSL	0.66	PSL	0.59
ASL	0.80	ASL	0.82
Cr	0.67	Cr	0.75

Performed RM-ANOVA with Greenhouse-Geisser correction,

Cr: crowding,
(M1-6: n=40, P,A,AWC, AWM, AL, Cr: n=20)

2) Effect of upper or lower position on the dental measurements in the three dental models

The effect of an upper or lower position on dental measurements in the three dental models used was also evaluated (Table 10), but no statistically significant effect was found. There was also no interaction between an upper or lower position and the precision of dental measurements made using the three dental models.

Table 10. Effect of position on dental measurements in the three dental models

	P
M1	0.54
M2	0.56
M3	0.84
M4	0.39
M5	0.75
M6	0.96
PSL	0.82
ASL	0.66
Cr	0.52

Performed RM-ANOVA with Greenhouse-Geisser correction,

Cr: crowding,
(M1~M6: n=40, P,A,AWC, AWM, AL, Cr: n=20)

Ⅳ. Discussion

To evaluate the validity of digital model analysis, intraoral-scan models that were generated by scanning actual patients in clinical conditions were used in this study, unlike previous studies of the validity of intraoral-scan models, which mostly used reference models (Ender and Mehl, 2013; Patzelt et al., 2014). In addition, the dentition of patients with various ranges of crowding was scanned to confirm whether digital intra-oral scanning is a sufficiently reliable method for use in orthodontic diagnoses in patients with severe crowding.

The reproducibility of both caliper measurements and digital measurements were confirmed by calculating the ICC values. The ICC range was 0.98–1.00 for cast models and 0.96–1.00 for digital models. In the study by Hazeveld and colleagues (Hazeveld et al., 2014), the ICC of the mesio-distal width of teeth in a 3D-printed model as measured by caliper was 0.962–0.999, which was similar to that obtained in this study.

Our study evaluated differences in measurements for each model generated by the method of fabrication of the models and the way in which measurements were performed. Thus, it was necessary that only one examiner perform all measurements, to exclude errors caused by selecting different measuring points; moreover, a 3D-measurement program was used to minimize measuring errors.

There was no significant difference in the measurement values of overjet and overbite in the three models. Reuschl et al. (2015) compared cast models with cast-scan models in 19 patients and reported that there was a significant difference in overjet, but not in overbite. Asquith and McIntyre (2012) stated that errors of more than 0.5 mm are clinically unacceptable for a single tooth or overjet. It may be appropriate to make diagnostic decisions based on values of overjet and overbite measured from digital models if a checking bite was performed during the intraoral scanning process.

There was no significant difference in the arch width of the canine (AWC) on either the maxilla or the mandible among cast models, cast-scan models, and intraoral-scan models; this finding corresponds with the results of the study by Rueschl et al. (2015). However, there was a significant difference in AL between cast and intraoral scans in both the maxilla and mandible, as well as in the arch width of molar (AWM) between the cast and intraoral scans in the mandible. This may be explained by arch distortion (value: < 170 µm) that occurs during the scanning process (Ender and Mehl, 2013), which makes the arch width seem wider than it actually is in the molar area, and causes it to be shifted forward into the incisal area, where it makes AWM and AL appear to be greater. Asquith and McIntyre (2012) mentioned that it is not appropriate to use measurements clinically if the errors in linear measurements exceeds 5% of the linear measurements made prior to orthodontic diagnosis. Although the mean differences in AWM and AL between the cast scan and the intraoral scan was significantly different in our study and were at a clinically acceptable level, further studies on the clinical validity of this approach is required.

There was significant difference between the cast model and intraoral-scan model at the lateral incisor, 1^{st} and 2^{nd} premolar, and 1^{st} molar in the maxilla, and at the 1^{st} and 2^{nd} premolar in the mandible. These differences could be explained by (1) the distortion that occurred when fabricating a cast model using an alginate impression, (2) distortion that occurred during intraoral scanning, and (3) differences in the measuring method.

First, differences between the cast model and intraoral-scan model or cast-scan model and intraoral-scan model includes the error that occurs when the cast model is fabricated using an alginate impression. Although some alginate impression models are clinically acceptable for diagnosis, treatment planning, and fabrication of orthodontic appliances (Anusavice and Phillips, 2003), fine details of the tooth anatomy might be lost because of the potential shrinkage of alginate upon desiccation (Grunheid et al., 2014). A suitable cast model can be created only by pouring the plaster immediately after taking the impression (Coleman et al., 1979; Miller, 1975); although we did this, distortion of the cast model could not be completely controlled. It has been reported that dimensional shrinkage of alginate is 0.44% per hour and dimensional expansion of plaster is 0.3% in 2 h (Kim, 2008).

Second, limited space and moisture in the mouth during the intraoral scanning process may have caused significant differences, especially in posterior teeth. Flugge et al. (2013) mentioned that the low precision of intraoral-scan models might be due to patient movement, limited intraoral space, intraoral humidity, and saliva flow.

Third, the error could be explained by differences in the measuring method between the cast model and digital model. Unlike in the direct caliper-based measuring method, there is no physical barrier dictating the placement of the caliper on measuring points when measuring a digital model. Thus, as long as a careful measuring point is selected on the computer screen, it would be reasonable to believe that digital measurements are more valid than those made using calipers on plaster (Stevens et al., 2006).

Clearly, none of the three methods tested here can produce an exact replica of the patient's actual dentition. It is known that changes in the measurements of incisor height of an alginate impression remain within 0.27 mm in the 12-h period after impression taking (Lee et al., 2016). Instead of using a cast model as gold standard, as was done in previous studies (Goonewardene et al., 2008; Horton et al., 2010; Keating et al., 2008; Leifert et al., 2009; Mullen et al., 2007; Quimby et al., 2004; Santoro et al., 2003; Stevens et al., 2006), we tried to compare diagnoses made using digital models and those made conventionally based on cast models.

In previous studies that compared the cast model to a digital model, it had been suggested that an acceptable level of orthodontic reliability for measurement of the mesio-distal width of a single tooth is a range of error of about 0.20–0.27 mm (Bell et al., 2003; Bishara et al., 1986; Bishara et al., 1989; Costalos et al., 2005; Fleming et al., 2011; Mayers et al., 2005; Mullen et al., 2007; Quimby et al., 2004; Santoro et al., 2003; Schirmer and Wiltshire, 1997; Stevens et al., 2006). The mean difference in the mesio-distal width in this study ranged from -0.02 mm to 0.12 mm, indicating that errors in model analysis using a digital model were at a clinically acceptable level.

In the present study, the samples were divided according to the amount of crowding. In the SC group, there was a significant difference in width of the upper lateral incisor and premolars between the cast model and the intraoral-scan model, while there was a significant difference in the premolars and 1st molar among all three types of models in the MC group. Unlike the MC group, in which significant differences were present at all posterior teeth, there was a significant difference only in the maxillary lateral incisor between the cast model and the digital model in the SC group. This may be due to the difficulty of reproducing the proximal surface of the tooth in a model with marked crowding during the process of reconstructing data into an STL file, where the inner part of the model is represented as a hollow object (Im et al., 2014). There may have been more significant differences in the MC group than in the SC group in posterior teeth because of difficulties in measuring the mesio-distal width of teeth. In the MC group, the most-distal points (or most-mesial points) of posterior teeth, are frequently selected as a measuring point, where they make complete contact with adjacent teeth. On the other hand, in the SC group, most measuring points were exposed because of mesial tipping or crowding, and thus error during

measurement was reduced. These results are in contrast to those of previous studies (Im et al., 2014; Redlich et al., 2008); thus, further studies, not only about the total amount of crowding, but also studies of the precision of linear measurements of crowding in specific locations, are needed. When determining the mean difference in the amount of crowding, cast analysis yielded higher values than digital analysis, except for maxillary measurements in the MC group. Im et al. (2014) and Reuschl et al. (2015) reported that the mesio-distal widths of most teeth would be underestimated in a digital model compared to in a real tooth. This tendency needs to be considered when diagnosing based on digital models without a cast, as most clinicians are used to diagnose and establish treatment plans based on cast model analysis.

To evaluate the inaccuracy of measurements of tooth width in digital models with severe crowding, as mentioned in a previous study (Redlich et al., 2008), the interaction effect of the severity of crowding was confirmed on the dental measurements in three dental models. There was no interaction between severe crowding (> 4.5 mm) and the precision of dental measurements in the three dental models studied here. Additionally, we found that different levels of difficulty in scanning between the maxillary and mandibular dentition caused by the tongue had no effect.

There were some differences in the precision of space analysis between different crowding groups, but these did not reach statistical significance in interaction analyses. Thus, using an intraoral scanner for diagnostic purposes in the orthodontic clinic is appropriate and useful. Moreover, cast models that have already been stored can be replaced with cast-scan models for ease of storage. Further studies about the effect of the state or distribution of crowding on the precision of linear measurements, by analyzing teeth in specific areas with severe crowding, are needed.

Ⅴ. Conclusion

By comparing values of linear measurement and amounts of crowding of the cast models, the cast-scan models and the intraoral-scan models, the following conclusions were drawn.

1. **Linear measurements made using digital calipers on a cast model and using software on a digital model were both reproducible.**
2. **The mean differences ranged from -0.01 mm to 0.12 mm on the mesio-distal width of teeth, -0.30 mm to 0.45 mm in the arch width, and 0.14 to 1.35 mm of arch length.**
3. **In the MC group, there was a significant difference in the amount of crowding between cast and intraoral scans of the maxilla (mean difference: 0.78 mm; $p < 0.05$). There was no significant difference in the amount of crowding in the mandible.**
4. **In the SC group, there was a significant difference in the amount of crowding in both the maxilla and the mandible between the cast and intraoral scans (mean difference: 0.86 mm and 0.51 mm, respectively; $p < 0.05$).**
5. **There was no interaction between the amount of crowding and the precision of the linear measurements made in the three models ($p > 0.05$).**

There were significant differences in the amount of crowding, although these did not have a clinically meaningful effect, and there was no relationship to the severity of crowding. Thus, as with cast models, digital models can also be used for measuring crowding for orthodontic diagnoses in both patients with mild and those with severe crowding. However, the tendency for detection of less crowding in digital models should be considered.

VI. References

Anusavice KJ, Phillips RW: Phillips' science of dental materials. 11th ed. Saunders, St. Louis, Mo., 2003, p. xxv, 805 p.

Asquith JA, McIntyre GT: Dental arch relationships on three-dimensional digital study models and conventional plaster study models for patients with unilateral cleft lip and palate. *Cleft Palate Craniofac J* 49(5): 530-534, 2012.

Bell A, Ayoub AF, Siebert P: Assessment of the accuracy of a three-dimensional imaging system for archiving dental study models. *J Orthod* 30(3): 219-223, 2003.

Bishara SE, Fernandez Garcia A, Jakobsen JR, Fahl JA: Mesiodistal crown dimensions in Mexico and the United States. *Angle Orthod* 56(4): 315-323, 1986.

Bishara SE, Jakobsen JR, Abdallah EM, Fernandez Garcia A: Comparisons of mesiodistal and buccolingual crown dimensions of the permanent teeth in three populations from Egypt, Mexico, and the United States. *Am J Orthod Dentofacial Orthop* 96(5): 416-422, 1989.

Brawek PK, Wolfart S, Endres L, Kirsten A, Reich S: The clinical accuracy of single crowns exclusively fabricated by digital workflow--the comparison of two systems. *Clin Oral Investig* 17(9): 2119-2125, 2013.

Coleman RM, Hembree JH, Jr., Weber FN: Dimensional stability of irreversible hydrocolloid impression material. *Am J Orthod* 75(4): 438-446, 1979.

Correia GD, Habib FA, Vogel CJ: Tooth-size discrepancy: a comparison between manual and digital methods. *Dental Press J Orthod* 19(4): 107-113, 2014.

Costalos PA, Sarraf K, Cangialosi TJ, Efstratiadis S: Evaluation of the accuracy of digital model analysis for the American Board of Orthodontics objective grading system for dental casts. *Am J Orthod Dentofacial Orthop* 128(5): 624-629, 2005.

da Costa JB, Pelogia F, Hagedorn B, Ferracane JL: Evaluation of different methods of optical impression making on the marginal gap of onlays created with CEREC 3D. *Oper Dent* 35(3): 324-329, 2010.

Del Corso M, Aba G, Vazquez L, Dargaud J, Dohan Ehrenfest DM: Optical three-dimensional scanning acquisition of the position of osseointegrated implants: an in vitro study to determine method accuracy and operational feasibility. *Clin Implant Dent Relat Res* 11(3): 214-221, 2009.

Ender A, Mehl A: Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. *J Prosthet Dent* 109(2): 121-128, 2013.

Fleming PS, Marinho V, Johal A: Orthodontic measurements on digital study models compared with plaster models: a systematic review. *Orthod Craniofac Res* 14(1): 1-16, 2011.

Flugge 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* 144(3): 471-478, 2013.

Goonewardene RW, Goonewardene MS, Razza JM, Murray K: Accuracy and validity of space analysis and irregularity index measurements using digital models. *Aust Orthod J* 24(2): 83-90, 2008.

Grunheid T, McCarthy SD, Larson BE: Clinical use of a direct chairside oral scanner: an assessment of accuracy, time, and patient acceptance. *Am J Orthod Dentofacial Orthop* 146(5): 673-682, 2014.

Han UK, Vig KW, Weintraub JA, Vig PS, Kowalski CJ: Consistency of orthodontic treatment decisions relative to diagnostic records. *Am J Orthod Dentofacial Orthop* 100(3): 212-219, 1991.

Hazeveld A, Huddleston Slater JJ, Ren Y: Accuracy and reproducibility of dental replica models reconstructed by different rapid prototyping techniques. *Am J Orthod Dentofacial Orthop* 145(1): 108-115, 2014.

Horton HM, Miller JR, Gaillard PR, Larson BE: Technique comparison for efficient orthodontic tooth measurements using digital models. *Angle Orthod* 80(2): 254-261, 2010.

Im J, Cha JY, Lee KJ, Yu HS, Hwang CJ: Comparison of virtual and manual tooth setups with digital and plaster models in extraction cases. *Am J Orthod Dentofacial Orthop* 145(4): 434-442, 2014.

Keating AP, Knox J, Bibb R, Zhurov AI: A comparison of plaster, digital and reconstructed study model accuracy. *J Orthod* 35(3): 191-201; discussion 175, 2008.

Kim KN: Dental Materials. Gun-ja, 2008, p. 127,159.

Kurbad A: Impression-free production techniques. *Int J Comput Dent* 14(1): 59-66, 2011.

Lee SM, Hou Y, Cho JH, Hwang HS: Dimensional accuracy of digital dental models from cone-beam computed tomography scans of alginate impressions according to time elapsed after the impressions. *Am J Orthod Dentofacial Orthop* 149(2): 287-294, 2016.

Leifert MF, Leifert MM, Efstratiadis SS, Cangialosi TJ: Comparison of space analysis evaluations with digital models and plaster dental casts. *Am J Orthod Dentofacial Orthop* 136(1): 16 e11-14; discussion 16, 2009.

Luthardt RG, Kuhmstedt P, Walter MH: A new method for the computer-aided evaluation of three-dimensional changes in gypsum materials. *Dent Mater* 19(1): 19-24, 2003.

Luthardt RG, Loos R, Quaas S: Accuracy of intraoral data acquisition in comparison to the conventional impression. *Int J Comput Dent* 8(4): 283-294, 2005.

Mayers M, Firestone AR, Rashid R, Vig KW: Comparison of peer assessment rating (PAR) index scores of plaster and computer-based digital models. *Am J Orthod Dentofacial Orthop* 128(4): 431-434, 2005.

Miller MW: Syneresis in alginate impression materials. *Br Dent J* 139(11): 425-430, 1975.

Mullen SR, Martin CA, Ngan P, Gladwin M: Accuracy of space analysis with emodels and plaster models. *Am J Orthod Dentofacial Orthop* 132(3): 346-352, 2007.

Patzelt SB, Emmanouilidi A, Stampf S, Strub JR, Att W: Accuracy of full-arch scans using intraoral scanners. *Clin Oral Investig* 18(6): 1687-1694, 2014.

Quimby ML, Vig KW, Rashid RG, Firestone AR: The accuracy and reliability of measurements made on computer-based digital models. *Angle Orthod* 74(3): 298-303, 2004.

Redlich M, Weinstock T, Abed Y, Schneor R, Holdstein Y, Fischer A: A new system for scanning, measuring and analyzing dental casts based on a 3D holographic sensor. *Orthod Craniofac Res* 11(2): 90-95, 2008.

Reuschl RP, Heuer W, Stiesch M, Wenzel D, Dittmer MP: Reliability and validity of measurements on digital study models and plaster models. *Eur J Orthod*, 2015.

Rudolph H, Luthardt RG, Walter MH: Computer-aided analysis of the influence of digitizing and surfacing on the accuracy in dental CAD/CAM technology. *Comput Biol Med* 37(5): 579-587, 2007.

Santoro M, Galkin S, Teredesai M, Nicolay OF, Cangialosi TJ: Comparison of measurements made on digital and plaster models. *Am J Orthod Dentofacial Orthop* 124(1): 101-105, 2003.

Schirmer UR, Wiltshire WA: Manual and computer-aided space analysis: a comparative study. *Am J Orthod Dentofacial Orthop* 112(6): 676-680, 1997.

Stein JM: Stand-alone scanning systems simplify intraoral digital impressioning. *Compend Contin Educ Dent* 32 Spec No 4: 56, 58-59, 2011.

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

Syrek A, Reich G, Ranftl D, Klein C, Cerny B, Brodesser J: Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active wavefront sampling. *J Dent* 38(7): 553-559, 2010.

Tomassetti JJ, Taloumis LJ, Denny JM, Fischer JR, Jr.: A comparison of 3 computerized Bolton tooth-size analyses with a commonly used method. *Angle Orthod* 71(5): 351-357, 2001.

Wiranto MG, Engelbrecht WP, Tutein Nolthenius HE, van der Meer WJ, Ren Y: Validity, reliability, and reproducibility of linear measurements on digital models obtained from intraoral and cone-beam computed tomography scans of alginate impressions. *Am J Orthod Dentofacial Orthop* 143(1): 140-147, 2013.

국문 요약

총생양에 따른 디지털 치아 모형 분석의 정밀도

연세대학교 대학원 치의학과

<지도교수 : 차정열>

윤재희

본 연구에서는 다양한 총생을 가진 환자의 석고모형과 석고모형을 스캔한 디지털 모형, 구강내 스캔 디지털 모형에서 치아의 근원심 길이와 총생 측정의 일치도를 평가하였다. 또한, 이를 토대로 디지털 모형을 토대로 진단시 고려해야 할 사항에 대해 고찰해 보았다.

치료 전 구강내 스캔을 시행하고 간접부착을 위한 석고모형이 있는 58 명을 대상으로 연구를 진행하였다. 석고모형에서 처음 측정한 총생의 크기를 기준으로 상, 하악에서 mild crowding group (<3.0 mm) 20 개와 moderate to severe crowding group(>4.5 mm) 20 개씩 선택하여 해당 모형에 대해 석고모형을 스캔하였다. 구강내 스캔 디지털모형(IS), 석고모형(C), 석고모형을 스캔한 디지털모형(CS) 총 세가지 모형에서 모형계측을 2 회씩 시행하였다. 이를 토대로 각 모형에서 2 회 측정의 재현도와, 2 회 측정값의 평균을 이용한 석고모형과 두 가지의 디지털모형에서의 측정값의 일치도를 비교한 결과 다음과 같은 결과를 얻었다.

1. 석고모형에서 digital caliper로 측정하는 모형계측방법과, digital model에서 measuring software (Rapidform XOR3, 64)를 사용한 모형계측방법 모두 재현성이 있었다.

2. 각 채득방식에 대한 평균오차의 범위는 치아근원심폭경에서 −0.01 mm~0.12 mm, 폭경분석에서 −0.30 mm~0.45 mm, 악궁 길이에서 0.14 mm~1.35 mm로 계측되었다.

3. 총생이 심하지 않은 그룹(MC group)에서 총생양은 상악에서 cast−intraoral scan 사이에서 평균오차 0.78 mm($p<0.05$)로 유의한 차이를 보였다.

4. 총생이 심한 그룹(SC group)에서 상악과 하악의 총생양은 cast−intraoral scan 사이에서 각각 평균오차 0.86 mm, 0.51mm 로, 통계적으로 유의한 차이를 보였다 ($p<0.05$).

5. 총생 계측에 대한 교호효과 분석에서 모형채득방식과 총생의 정도에 대해 유의한 결과차이가 없었다 ($p>0.05$).

이상의 결과로 임상적으로 디지털 모형을 이용한 모형계측이 가능하며 총생의 양에 관계 없이 공간 분석에도 임상적으로 신뢰할만한 결과를 얻을 수 있었다. 그러나 디지털 모형에서의 총생의 양이 석고모형에서보다 더 적게 측정되는 점을 고려해야한다.

핵심이 되는 말: 석고모형스캔, 구강내스캔, 길이측정, 총생, 디지털 모형, 공간분석