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치의학 석사학위 논문

Accuracy of two different intraoral scanners in single-tooth abutment : In Vitro Two-Dimensional Analysis

단일치아 지대주에서 2종의구강스캐너의 2차원분석에 따른 정확도 비교

2019 년 2 월

서울대학교 대학원
치의학과
맹 지 연

ABSTRACT

Accuracy of two different intraoral scanners in single-tooth abutment : In Vitro Two-Dimensional Analysis

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(Directed by Prof. Young-Jun Lim, DDS, MSD, Ph.D.)

1. Purpose

Studies assessing the accuracy of intraoral scanners with 2-dimensional analysis method are rare. The aim of this study was to evaluate accuracy outcomes of two types of scanners through 2-dimensional analyses at 5 digital cross-sections of single-tooth

abutment, and to evaluate accuracy of individual scanners.

2. Methods

This study utilized stone models of 13 participants of clinical study (IRB No. CDE17004) performed in Seoul National University Dental Hospital (SNUDH) from December 7, 2017 to August 22, 2018. The study sample consisted of 6 male and 7 female with an average age of 53.92 (± 10.43). Two types of intraoral scanner systems were tested for this study: Trios 3® (3 Shape, Copenhagen, Denmark) and EzScan® (Vatech, Hwaseong, Korea). Identica Hybrid® (Medit Co, Seoul, Korea) was used to create digital reference data.

Using Best-Fit Alignment function in Geomagic Control X™ (3Dsystems, RockHill, USA), superimposed 3D data files were sectioned to five different planes: buccal-lingual section (BL, group 1), mesial-distal section (MD, group 2), transverse high section (TH, group 3), transverse middle section (TM, group 4), and transverse low section (TL, group 5).

Two dimensional deviations were numerically expressed with root mean square, positive deviation and negative deviation values.

Accuracy comparison between the two scanners in 5 cross-sectional groups was performed using paired t-test. For each scanners, t-test was used for comparison of BL and MD. One-way ANOVA test was used for comparison of TH, TM, and TL. Student-Newman-Keuls method was used for post-hoc test. All variables were presented with a mean and a standard deviation, where $p<0.05$ was considered statistically significant.

3. Results

Comparison of two-dimensional analysis for 2 intraoral scanners at

5 cross-sections showed statistically meaningful differences in group 1, 3, and 5. Trios 3 showed better results than EzScan at buccal-lingual section. At mesial-distal section, both Trios 3 and EzScan exhibited high deviation errors. Differences in groups 2, 4 were not statistically significant. At transverse-middle section, Trios 3 performance was superior to that of EzScan.

For both intraoral scanners, BL vs. MD comparison showed statistically significant differences in RMS and mean negative deviation values while mean positive deviation value did not. The results show that mesial-distal sections are more prone to error than buccal-lingual section, and statistically significant errors are expressed as negative deviations for both scanners. The transverse groups did not exhibit statistically significant difference.

4. Conclusion

Two-dimensional analysis is more insightful than three-dimensional analysis on single-tooth abutment area. In mesiodistal areas, rough prepped areas, and sharp edges where scanner accessibility is difficult, high deviation errors are shown.

Key Words : intraoral scanners, accuracy, 2-dimensional analysis, internal deviation, external deviation, RMS

Student Number : 2015-25325

Accuracy of two different intraoral scanners in single-tooth abutment : In Vitro Two-Dimensional Analysis

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Table of contents

Ⅰ. Introduction

Digitalization is no longer an unfamiliar concept; application of digitization is trending in social as well as dental community (Joda et al. 2017). There have been continuous movements to shift the paradigm to digital dentistry, and computer-assisted technologies have constantly evolved to meet the needs. In dental field where customization reflecting individual concerns is important, application of digitalization can make cumulative fallacies in treatment steps much more manageable. Fabrication of a digital copy in a virtual space followed by real-time modifications can result in what is closer to ideal prosthesis.

In CAD/CAM system, intraoral scanning for digital impression is a mandatory prerequisite for transition of overlapping intraoral images to a workable 3-dimensional virtual model. Because intraoral scanner scans teeth and surrounding anatomies that are required for treatment analysis, it is a pivotal process in determining overall treatment plan. Therefore, reliable digital impression may be considered the starting step for transition to a completely digitalized dental treatment.

Impression taking is a critical first step in fabrication of ideal prostheses. Currently, elastomeric conventional impression is the most commonly used method despite its inherent problems. Traditional method fails to overcome limitations such as long-term storage of physical treatment models, and distortion of impression (Patzelt et al.

2014). On the other hand, digitization of impression taking can provide several advantages. Digitalized impression taking not only rids physical space for long-term model storage but also aids in quick acquirement of three-dimensional diagnostic information and analysis that can be reflected in mid-treatment changes. In addition, patients are no longer exposed to gag-inducing procedure and foul smell and taste of impression materials. In other words, digitalized impression taking is more precise and flexible, less painful and time-consuming to both parties involved in dental treatment (Malik et al. 2018; van Noort 2012).

Although there is no doubt in the comfort that complete digital flow can provide to patients as well as clinicians and technicians, there are still doubts to whether digital technology such as intraoral scanners are sufficiently reliable enough to be applied to daily clinical environment. Even now, continuous efforts are made to assess and verify the accuracy and clinical applicability of existing and newly introduced intraoral scanners. However, there is no universal consensus. Clinicians and technicians are hence left to choose between digital and conventional procession (Joda et al. 2017).

General agreement among past systemic reviews is that intraoral scanners are not yet good enough to completely replace conventional impression methods. Currently, general consensus is that intraoral scanners exhibit poor performance for full-arch scans. Full-arch accuracies were significantly higher in conventional impressions. Inaccuracies seemed to compound in full-arch scans, demonstrating cumulated deviations especially in the molar areas (Atieh et al. 2017;

Güth et al. 2016; Malik et al. 2018; Patzelt et al. 2014). However, studies that provide evidence to support clinical acceptance of intraoral scan systems as the better option for dental impression are appearing as well (Ender et al. 2011).

For shorter span scans, intraoral digital scanners have shown more consistent positive results. Boeddinghaus et al. compared accuracy of three different intraoral scanners for single-tooth restoration by measuring marginal gap. Limited to the digital impression systems that the study used, the author concluded that intraoral scans revealed comparable accuracy in marginal fit (Boeddinghaus et al. 2015). However, another study on extraoral scanning of single-tooth abutment model reported different scanning systems showed different performance (Mandelli et al. 2017). As such, accuracy of even the simplest single-tooth are not stably trustworthy, a phenomenon that is not commonly found with traditional impression process. Furthermore, most reviews confirming digital systems as a viable alternative are limited to short span abutments of up to 3-units.

This underlying anxiety and inconvenience compels clinicians to return to complete or adjunctive conventional impression methods. Lack of clinical evidence also prevents clinicians to more actively practice complete digital processing despite its known potential advantages (Grünheid et al. 2014).

In prosthetic rehabilitation of single tooth, accuracy of abutment is important. Therefore, many previous and ongoing studies continue to test accuracy of intraoral scanners. In a recent study on accuracy of digital dental scanners, the author compared digital and conventional methods with teeth of nine different convergence angles. Three-dimensional analysis was performed for single-abutment tooth. RMS values revealed that abutment tooth geometry influenced conventional methods and model scanners, but intraoral scanners showed consistent accuracy regardless (Carbajal et al. 2017). Another study evaluated trueness and precision of six intraoral impression systems with varying scan techniques. Best-fit algorithm values achieved from three-dimensional superimposition of obtained virtual models revealed scan patterns did not significantly influence the accuracy of digital impression systems (Mennito et al. 2018). As such, most accuracy studies that concluded that current intraoral scanners perform with similar reliability used three-dimensional analysis. There is a lack of studies utilizing two-dimensional analysis on accuracy of intraoral scanners.

Most 3-dimensional comparative analyses use data of abutment tooth and its surrounding soft tissue for best-fit algorithm. Because the collected data includes adjacent anatomy, which is not the actual target of investigation, there is increase in data gathering (Güth et al. 2017). Best-fit algorithm with gathered data results in a mean value of both the abutment tooth and its surrounding tissue. Unfortunately, actual information that we need is the accuracy of abutment, not that of surrounding soft tissue. Increase in unnecessary data results in undesired correction of errors, and the tendency to modify actual errors makes it hard to identify accuracy deviations exclusively of a single tooth abutment.

Although surrounding anatomy is not excluded in scanned data, three-dimensional analyses do not include a process to compensate for this factor of fallacy. Therefore, with three-dimensional evaluation, it is easy to come to the conclusion that there is not a statistically significant difference amongst intraoral scanners. Three-dimensional analysis provides insufficient evidence to address existing errors of scanners. In fact, inability to point out inaccuracies often results in study conclusions that are rebated under clinical settings. For this reason, it seemed reasonable and necessary to come up with a 2-dimensional analysis method as a means to assess accuracy of intraoral scanners. Therefore, the aim of this study was to evaluate accuracy outcomes of two types of scanners through 2-dimensional analyses at 5 digital cross-sections (mesiodistal, buccolingual, high transverse, mid-transverse, low transverse) of single-tooth abutment, and to evaluate accuracy of individual scanners.

Ⅱ. Materials & Method

1. Materials

This study utilized cast models of 13 participants of clinical study (IRB No. CDE17004) “Clinical Evaluation of impression accuracy and fit of CAD/CAM fabricated monolithic zirconia single crowns based on newly developed intraoral and indirect digitalization” performed in Seoul National University Dental Hospital (SNUDH) from December 7,2017 to August 22, 2018. Casts for this study were fabricated via conventional impression method.

The study sample consisted of 6 male and 7 female with an average age of 53.92 (± 10.43). One tooth per study participant was selected for single-tooth abutment model: one 1^{st} premolar, three 2^{nd} premolar, and nine 1^{st} molar teeth(total number of teeth: 13). 8/13 were from maxilla and 5/13 were from mandible (Table 1).

Table 1 Teeth distribution data of 13 study participants. Data are presented as the number of participants.

			Number of participants	%
Tooth based (N=13)	Location	1st Premolar	1	7.7
		2nd Premolar	3	23.1
		1st Molar	9	69.2
	Jaw	Maxilla	8	61.5
		Mandible	5	38.5
Data are presented as number of participants.				

2. Methods

This study utilized cast models of 13 participants of clinical study (IRB No. CDE17004) "Clinical Evaluation of impression accuracy and fit of CAD/CAM fabricated monolithic zirconia single crowns based on newly developed intraoral and indirect digitalization" performed in Seoul National University Dental Hospital (SNUDH) from December 7,2017 to August 22, 2018. Casts for this study were fabricated via conventional impression method.

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Two types of intraoral scanner systems were tested for this study: Trios 3® (3 Shape, Copenhagen, Denmark) and EzScan® (Vatech, Hwaseong, Korea). Identica Hybrid® (Medit Co, Seoul, Korea) was used to create digital reference data of 13 models, which were also scanned using Trios 3 and EzScan in accordance with manufacturer's recommendation.

Scan files of 2 experimental scanners were exported to Geomagic Control X^{TM} (3Dsystems, RockHill, USA). Using Best-Fit Alignment function in Geomagic Control X, acquired data and reference data were 3-dimensionally aligned. The alignment was set to produce minimal error based on least square regression. Superimposed 3D data files were then cut to five cross-sectional planes: buccal-lingual section (BL, group 1), mesial-distal section (MD, group 2), transverse high section (TH, group 3), transverse middle section (TM, group 4), and transverse low section (TL, group 5) (Fig. 1).

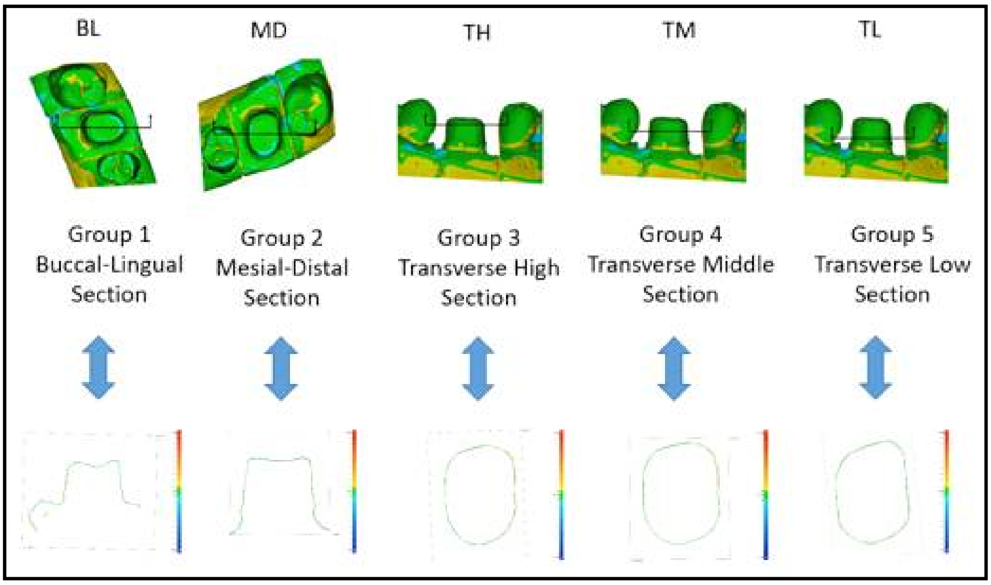

Fig. 1. Superimposed 3D data images were sectioned to five following 2D planes: buccal-lingual section (BL, group 1), mesial-distal section (MD, group 2), transverse high section (TH, group 3), transverse middle section (TM, group 4), and transverse low section (TL, group 5).

2D Compare function of Geomagic Control X was used to analyze discrepancies of superimposed cross-sections, with a set tolerance of ±0.07 mm and a maximum tolerance range of ±1.0 mm. For all comparisons, discrepancies between experimental file and reference file were expressed with a + or - sign, indicating deviation directionality (internal; -, external; +). These values were also visually expressed with a range of color-codes, where yellow lines indicate external deviations and cyan lines indicate internal deviations. The deviation (internal; -, external; +) and root mean square (RMS) were numerically quantified with a mean and standard deviation, respectively.

3. Statistical analysis

Statistical analysis was carried out with SigmaPlot (Systat Software Inc., San Jose, CA, USA). Comparison between the two scanners regarding accuracy in 5 cross-sectional groups was performed using paired t-test. For each of the scanners, t-test was used for comparison of BL (group 1) and MD (group 2). One-way ANOVA test was used for comparison of TH (group 3), TM (group 4), and TL (group 5). Student-Newman-Keuls method was used for post-hoc test. Mean and standard deviation were calculated based on data with a significance level of 0.05. All variables were presented with a mean and a standard deviation, where $p<0.05$ was considered statistically significant.

Ⅲ. Results

Accuracy of the two scanners against model scanner was measured from 5 different cross-sections. Color-coded image data of two-dimensional analysis on accuracy of Trios 3 and EzScan against model scanner can be seen in Figures 2-11. Differences of 13 study casts were numerically displayed with RMS, mean positive deviation, and mean negative deviation values (Table 2).

Table 2 Total raw data of intraoral scanners (Trios 3, EzScan) vs. model scanner (Identica) acquired from 13 study casts (Root Mean Square, mean positive deviation, mean negative deviation).

# 2D	Location	Model scanner vs. Intraoral scanner Identica T500 VS. Trios			Model scanner vs. Intraoral scanner Identica T500 vs. EzScan		
		Root Mean Square	Mean Positive Deviation	Mean Negative Deviation	Root Mean Square	Mean Positive Deviation	Mean Negative Deviation
1	Buccal-Lingual	0.0125	0.0109	-0.0086	0.0490	0.0457	-0.0378
	Mesial-Distal	0.0576	0.0458	-0.0326	0.0746	0.0691	-0.0570
	Transverse -high	0.0201	0.0165	-0.0172	0.0438	0.0364	-0.0250
	Transverse -middle	0.0218	0.0167	-0.0208	0.0525	0.0470	-0.0171
	Transverse -low	0.0316	0.0257	-0.0228	0.0871	0.0734	-0.0183
2	Buccal-Lingual	0.0110	0.0083	-0.0055	0.0527	0.0492	-0.0318
	Mesial-Distal	0.0306	0.0212	-0.0222	0.0521	0.0375	-0.0459
	Transverse -high	0.0105	0.0087	-0.0074	0.0492	0.0315	-0.0030
	Transverse -middle	0.0126	0.0101	-0.0077	0.0453	0.0304	-0.0091
	Transverse -low	0.0299	0.0247	-0.0134	0.0425	0.0378	-0.0296
3	Buccal-Lingual	0.0136	0.0095	-0.0115	0.0766	0.0513	-0.0766
	Mesial-Distal	0.0373	0.0133	-0.0312	0.0607	0.0336	-0.0667
	Transverse -high	0.0139	0.0134	-0.0083	0.0541	0.0374	-0.0557
	Transverse -middle	0.0120	0.0104	-0.0082	0.0516	0.0409	-0.0452
	Transverse -low	0.0141	0.0109	-0.0081	0.0479	0.0363	-0.0494
4	Buccal-Lingual	0.0118	0.0077	-0.0102	0.0828	0.0822	-0.0550
	Mesial-Distal	0.0245	0.0195	-0.0130	0.0490	0.0347	-0.0424
	Transverse -high	0.0211	0.0233	-0.0081	0.0533	0.0346	-0.0474
	Transverse -middle	0.0242	0.0242	-0.0089	0.0377	0.0265	-0.0366
	Transverse -low	0.0197	0.0188	-0.0126	0.0443	0.0299	-0.0473
5	Buccal-Lingual	0.0083	0.0075	-0.0056	0.0489	0.0395	-0.0411
	Mesial-Distal	0.0245	0.0134	-0.0356	0.1265	0.1388	-0.0595

	Transverse -high	0.0152	0.0123	−0.0109	0.1198	0.1405	−0.0772
	Transverse -middle	0.1323	0.0109	−0.0963	0.1084	0.1059	−0.0345
	Transverse -low	0.0152	0.0102	−0.0100	0.0552	0.0472	−0.0284
6	Buccal-Lingual	0.0673	0.0608	−0.0279	0.0531	0.0617	−0.0284
	Mesial-Distal	0.2566	0.1340	−0.5197	0.1912	0.1733	−0.0629
	Transverse -high	0.0446	0.0411	−0.0163	0.0551	0.0431	−0.0507
	Transverse -middle	0.0262	0.0239	−0.0083	0.0519	0.0431	−0.0349
	Transverse -low	0.0442	0.0321	−0.0077	0.0513	0.0392	−0.0372
7	Buccal-Lingual	0.0270	0.0192	−0.0226	0.0519	0.0528	−0.0237
	Mesial-Distal	0.0964	0.0637	−0.0628	0.0981	0.0697	−0.0658
	Transverse -high	0.0420	0.0392	−0.0316	0.0324	0.0295	−0.0176
	Transverse -middle	0.0402	0.0367	−0.0338	0.0380	0.0363	−0.0139
	Transverse -low	0.0411	0.0381	−0.0332	0.0370	0.0362	−0.0160
8	Buccal-Lingual	0.0150	0.0118	−0.0132	0.0477	0.0435	−0.0372
	Mesial-Distal	0.1105	0.0163	−0.1946	0.0921	0.0524	−0.0629
	Transverse -high	0.0218	0.0181	−0.0194	0.0484	0.0117	−0.0463
	Transverse -middle	0.0170	0.0167	−0.0112	0.0317	0.0242	−0.0264
	Transverse -low	0.0207	0.0201	−0.0131	0.0336	0.0271	−0.0288
9	Buccal-Lingual	0.0160	0.0116	−0.0145	0.0433	0.0337	−0.0339
	Mesial-Distal	0.0224	0.0133	−0.0169	0.0522	0.0374	−0.0442
	Transverse -high	0.0247	0.0112	−0.0260	0.0567	0.0220	−0.0518
	Transverse -middle	0.0163	0.0087	−0.0183	0.0413	0.0269	−0.0419
	Transverse -low	0.0147	0.0084	−0.0154	0.0419	0.0318	−0.0370
10	Buccal-Lingual	0.0144	0.0140	−0.0078	0.0534	0.0518	−0.0373
	Mesial-Distal	0.0534	0.0442	−0.0270	0.0637	0.0670	−0.0396
	Transverse -high	0.0137	0.0117	−0.0080	0.0450	0.0319	−0.0378
	Transverse -middle	0.0138	0.0123	−0.0104	0.0444	0.0373	−0.0220
	Transverse -low	0.0159	0.0128	−0.0155	0.0571	0.0519	−0.0217
11	Buccal-Lingual	0.0494	0.0475	−0.0306	0.0533	0.0470	−0.0369
	Mesial-Distal	0.0597	0.0499	−0.0864	0.0470	0.0355	−0.0404
	Transverse -high	0.0432	0.0468	−0.0185	0.0480	0.0347	−0.0494

	Transverse -middle	0.0394	0.0361	−0.0313	0.0422	0.0313	−0.0424
	Transverse -low	0.0508	0.0376	−0.0463	0.0696	0.0556	−0.0299
12	Buccal-Lingual	0.0235	0.0217	−0.0093	0.0838	0.0814	−0.0441
	Mesial-Distal	0.2294	0.0168	−0.2437	0.2084	0.0643	−0.1293
	Transverse -high	0.0281	0.0257	−0.0086	0.0762	0.0399	−0.0842
	Transverse -middle	0.0261	0.0259	−0.0102	0.0711	0.0667	−0.0307
	Transverse -low	0.0250	0.0240	−0.0179	0.0791	0.0688	−0.0107
13	Buccal-Lingual	0.0105	0.0065	−0.0089	0.0499	0.0326	−0.0457
	Mesial-Distal	0.1090	0.0575	−0.0599	0.1202	0.0844	−0.0418
	Transverse -high	0.0179	0.0127	−0.0161	0.0326	0.0105	−0.0327
	Transverse -middle	0.0179	0.0143	−0.0153	0.0287	0.0171	−0.0264
	Transverse -low	0.0232	0.0071	−0.0218	0.0425	0.0349	−0.0388

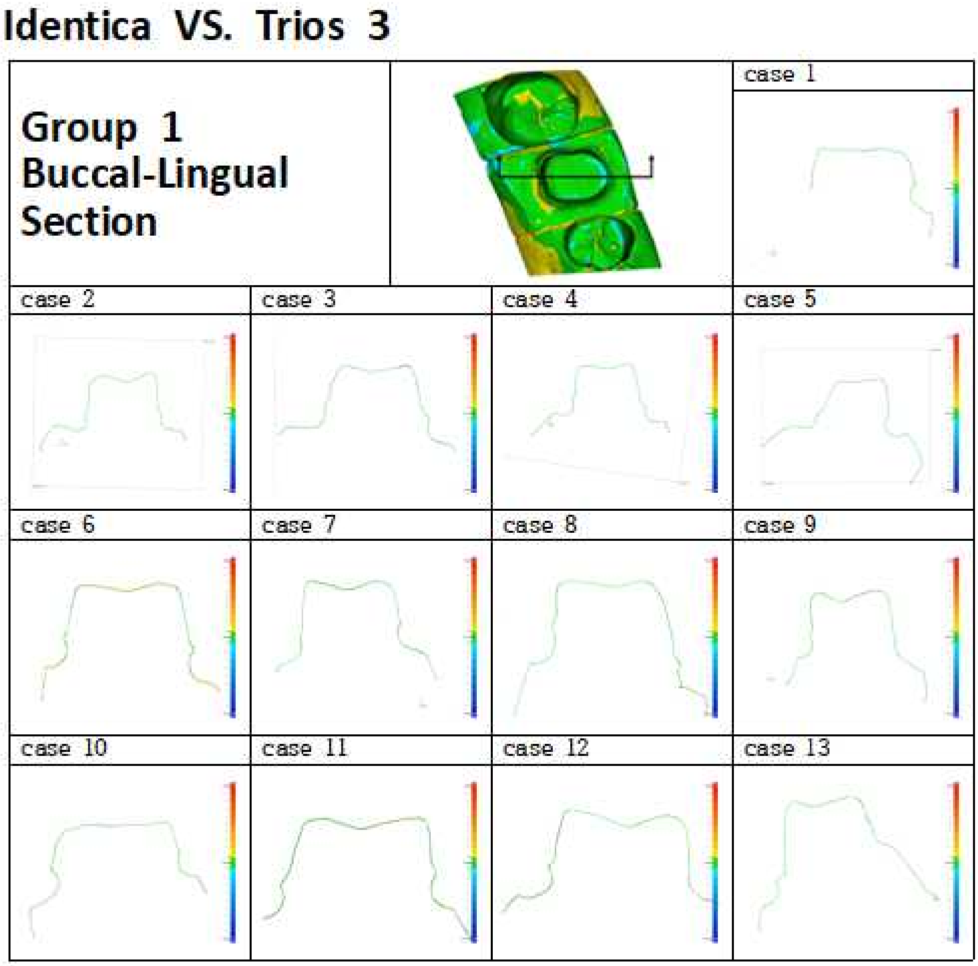

Figure 2. Result of two-dimensional analysis in Identica vs. Trios 3 at buccal-lingual section. Yellow lines indicate external deviations and cyan lines indicate internal deviations.

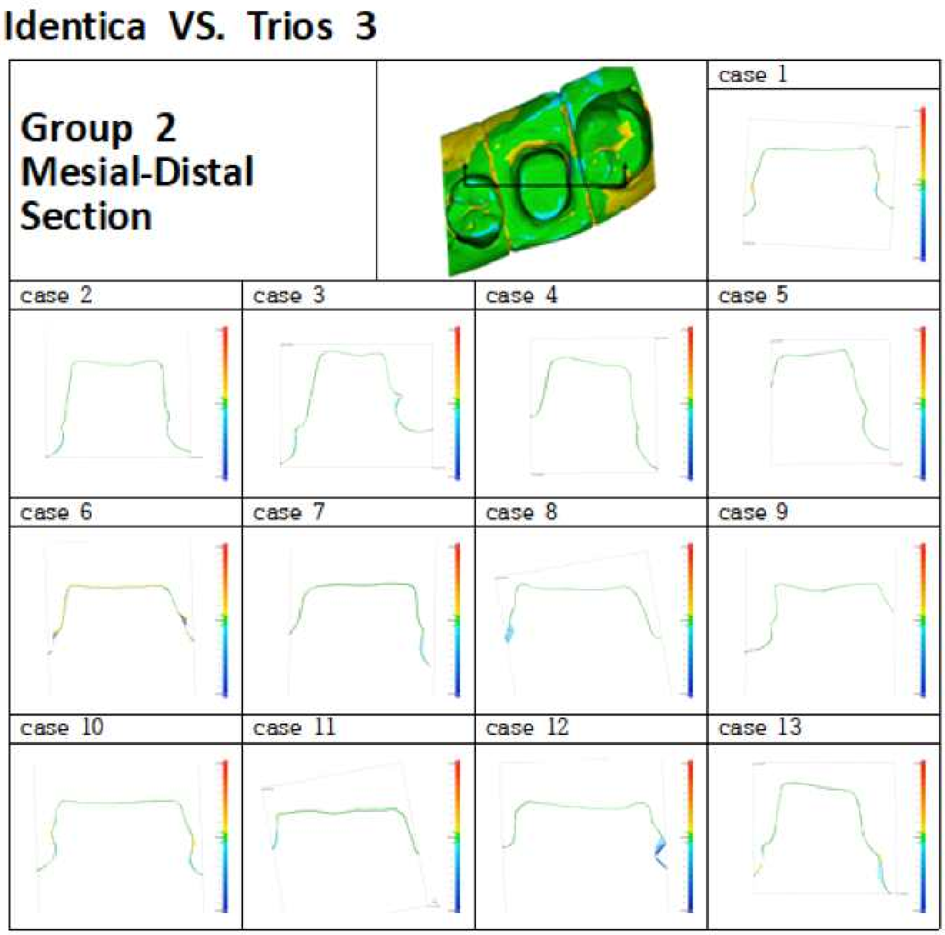

Figure 3. Result of two-dimensional analysis in Identica vs. Trios 3 at mesial-distal section. Yellow lines indicate external deviations and cyan lines indicate internal deviations.

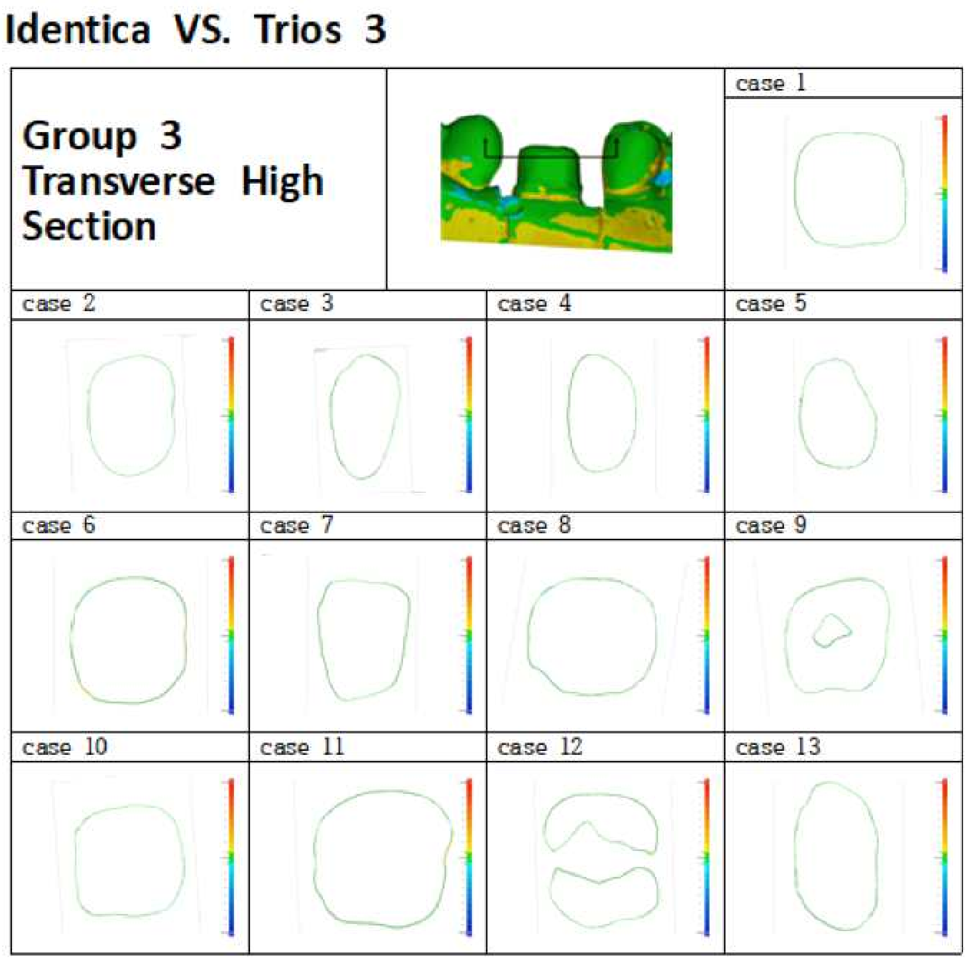

Figure 4. Result of two-dimensional analysis in Identica vs. Trios 3 at transverse high section. Yellow lines indicate external deviations and cyan lines indicate internal deviations.

Identica VS. Trios 3

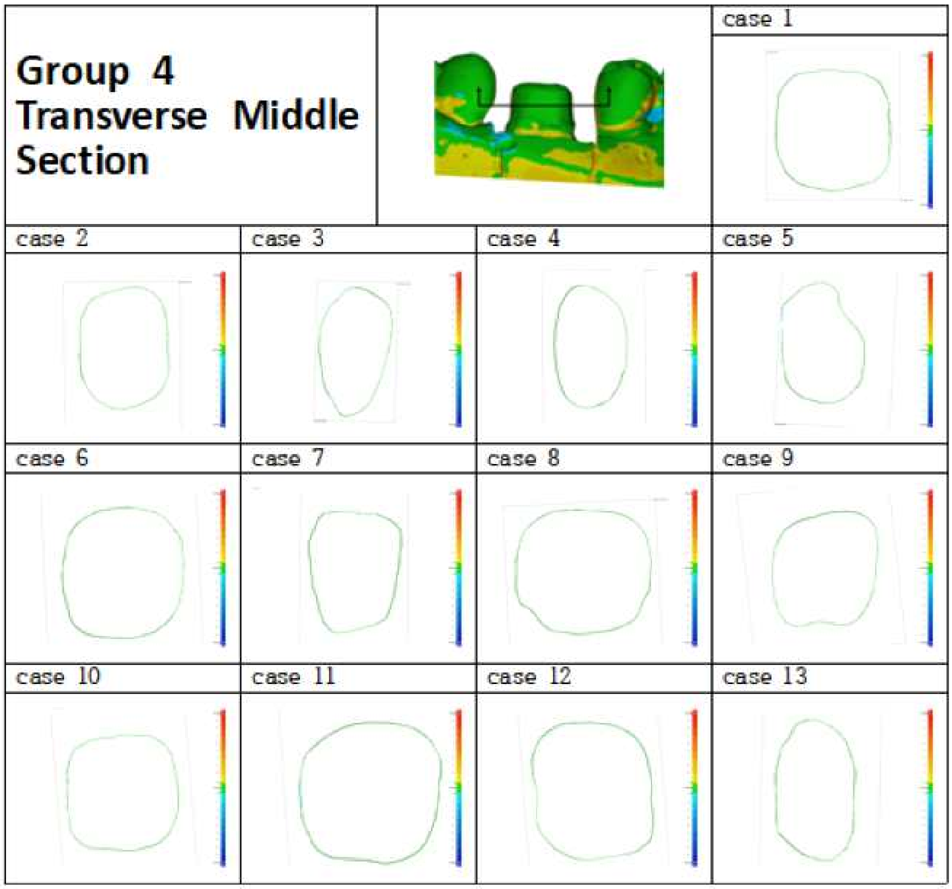

Figure 5. Result of two-dimensional analysis in Identica vs. Trios 3 at transverse middle section. Yellow lines indicate external deviations and cyan lines indicate internal deviations.

Identica VS. Trios 3

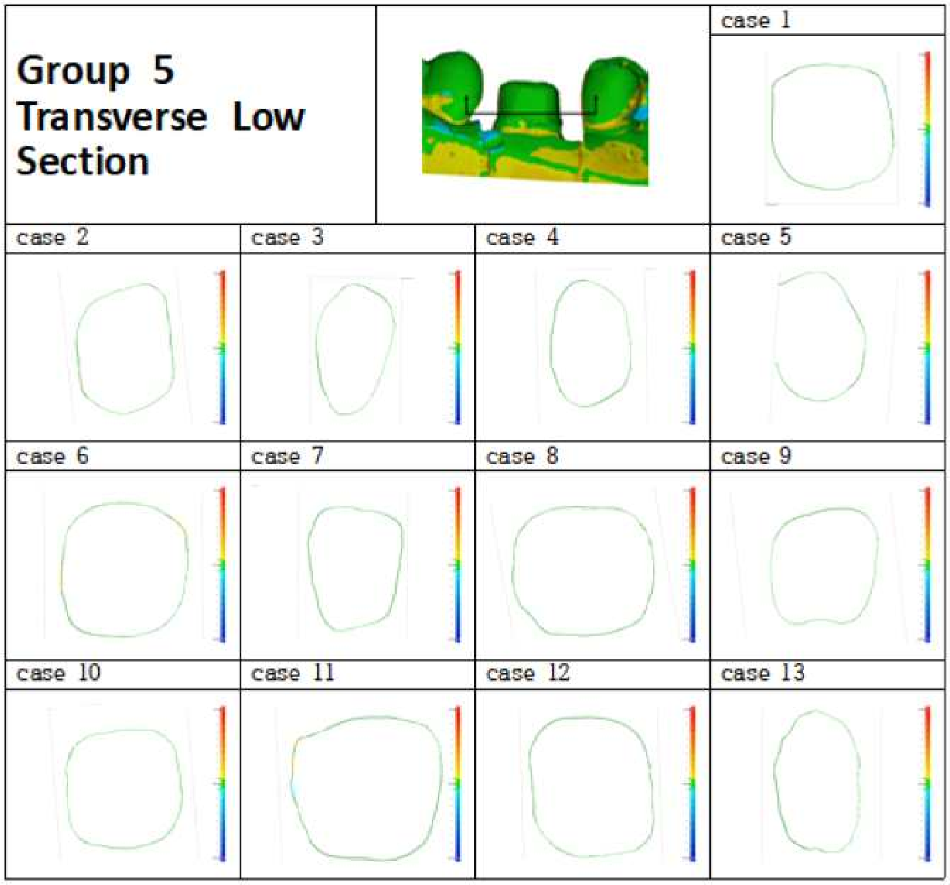

Figure 6. Result of two-dimensional analysis in Identica vs. Trios 3 at transverse low section. Yellow lines indicate external deviations and cyan lines indicate internal deviations.

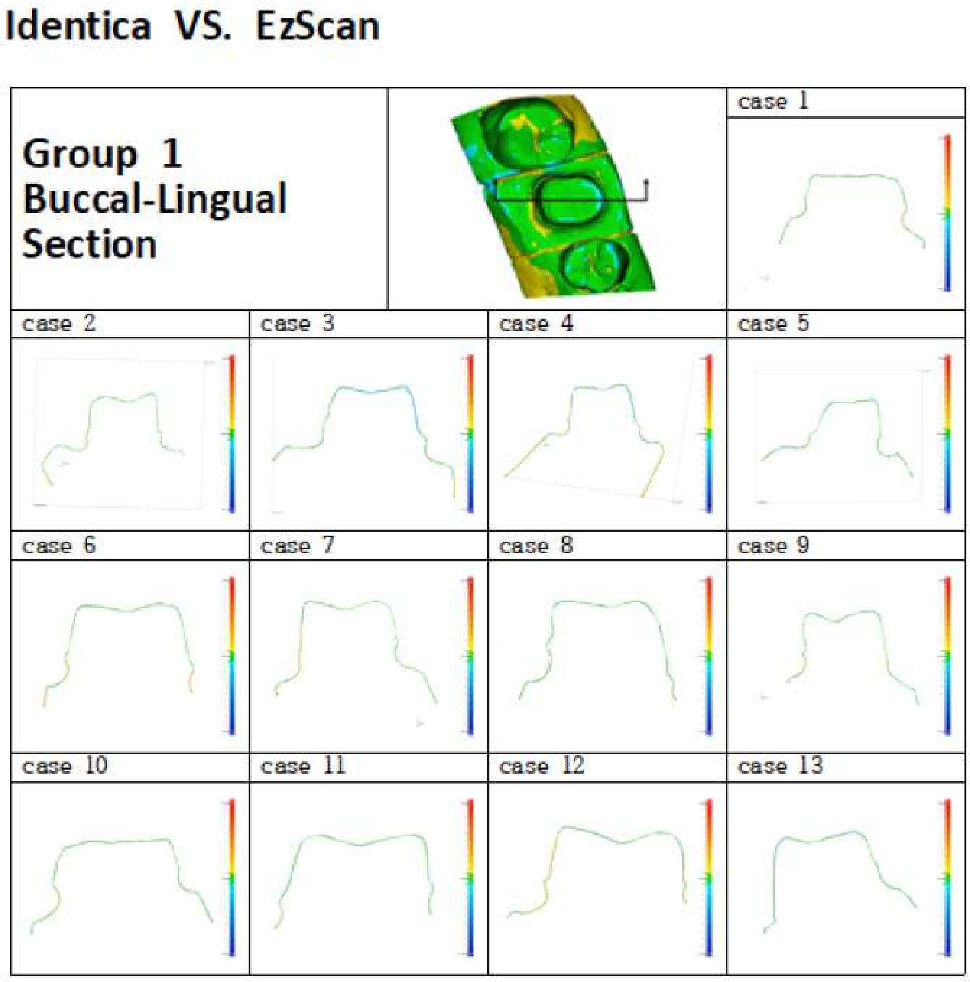

Figure 7. Result of two-dimensional analysis in Identica vs. EzScan at buccal-lingual section. Yellow lines indicate external deviations and cyan lines indicate internal deviations.

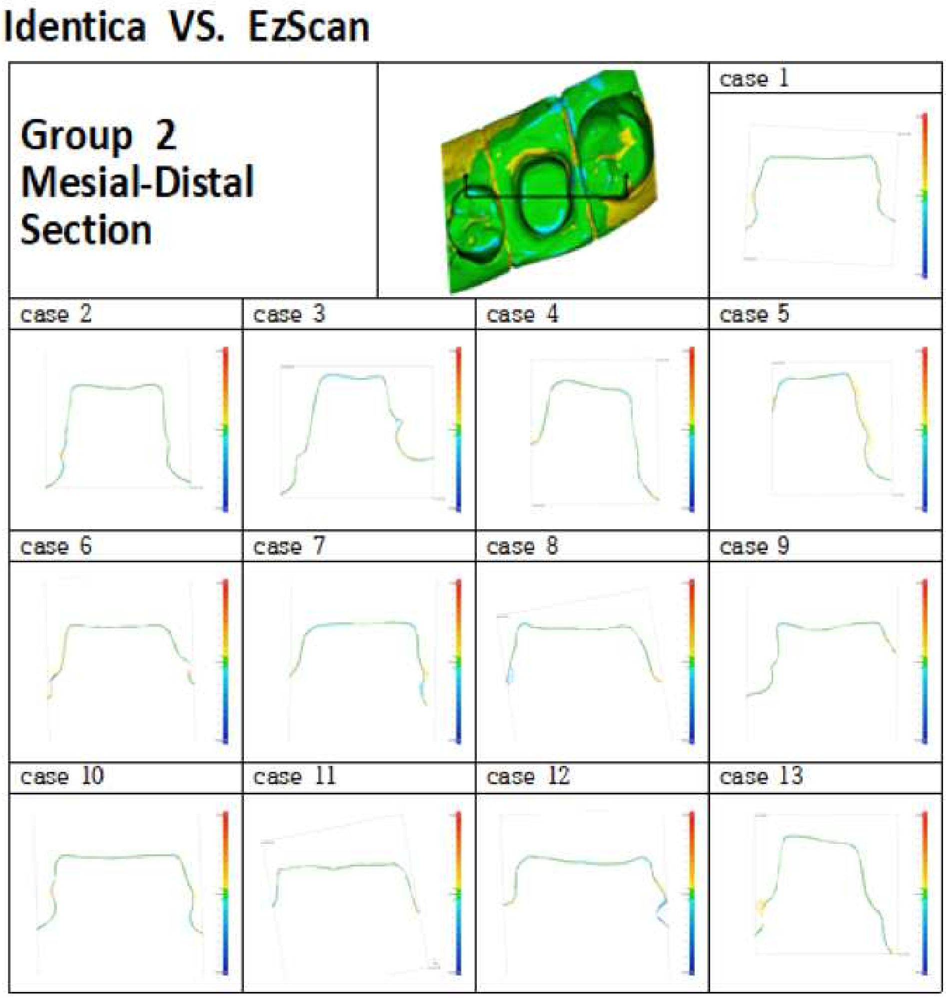

Figure 8. Result of two-dimensional analysis in Identica vs. EzScan at mesial-distal section. Yellow lines indicate external deviations and cyan lines indicate internal deviations.

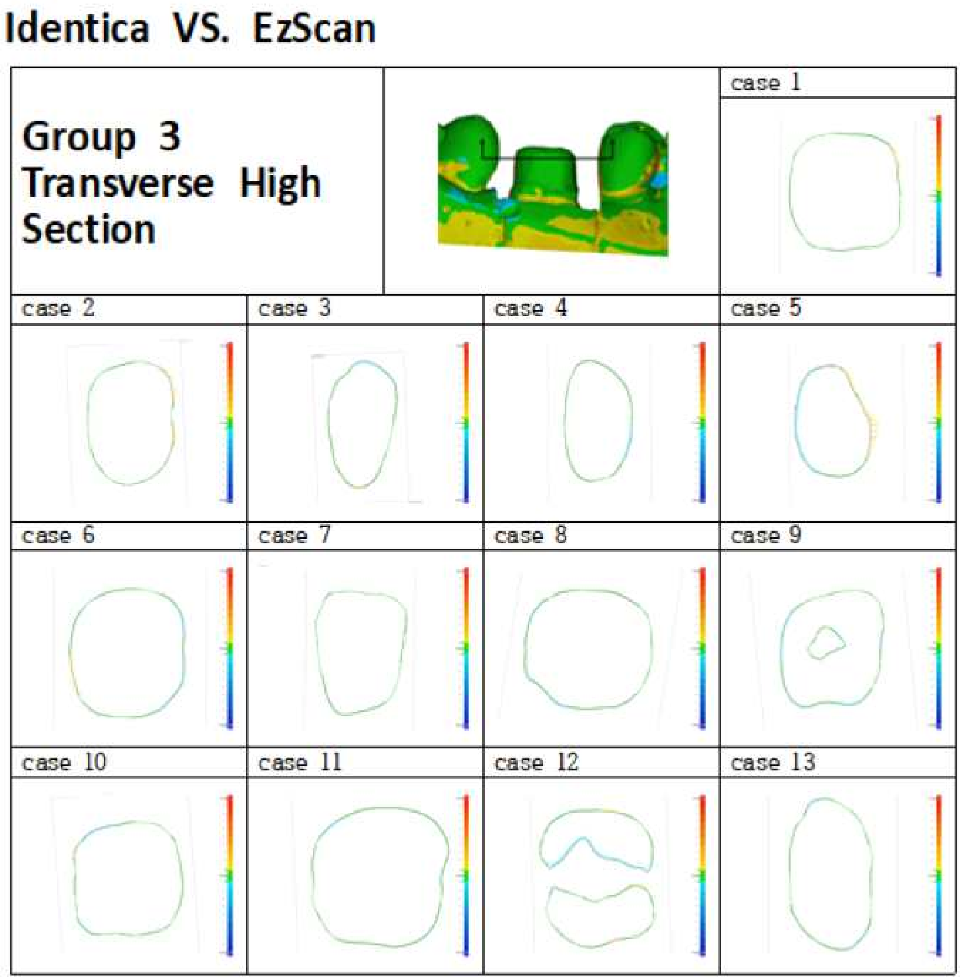

Figure 9. Result of two-dimensional analysis in Identica vs. EzScan at transverse high section. Yellow lines indicate external deviations and cyan lines indicate internal deviations.

Identica VS. EzScan

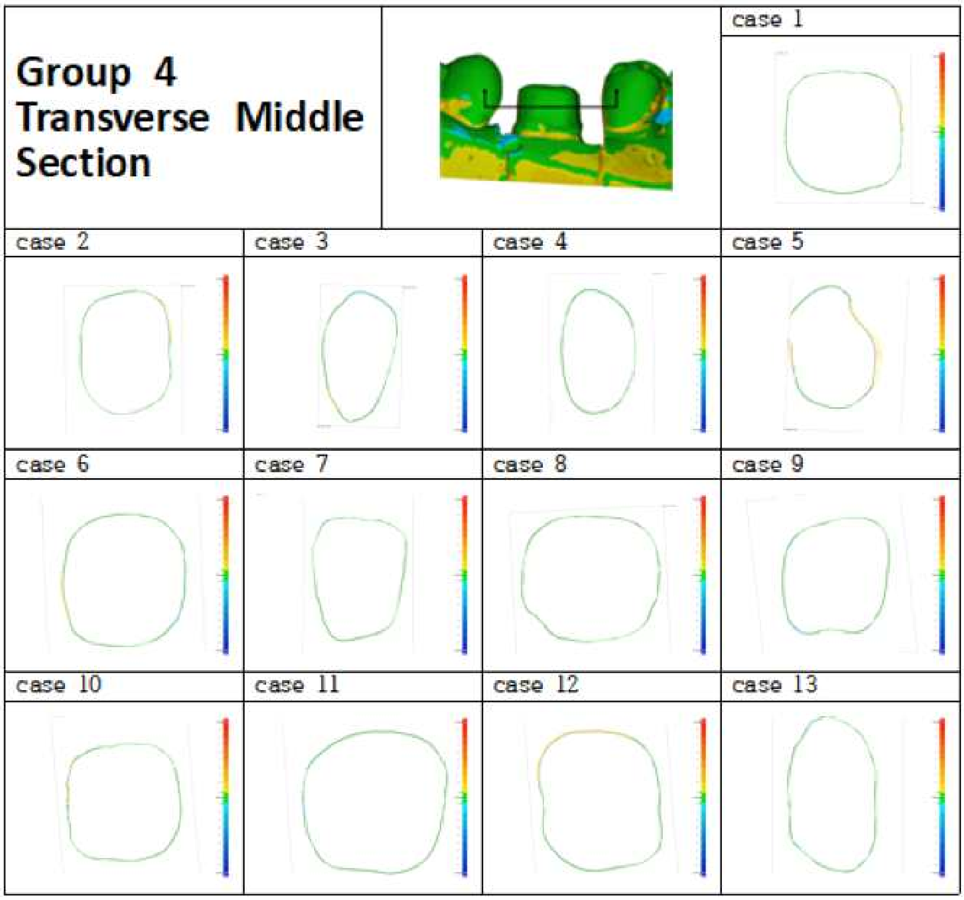

Figure 10. Result of two-dimensional analysis in Identica vs. EzScan at transverse middle section. Yellow lines indicate external deviations and cyan lines indicate internal deviations.

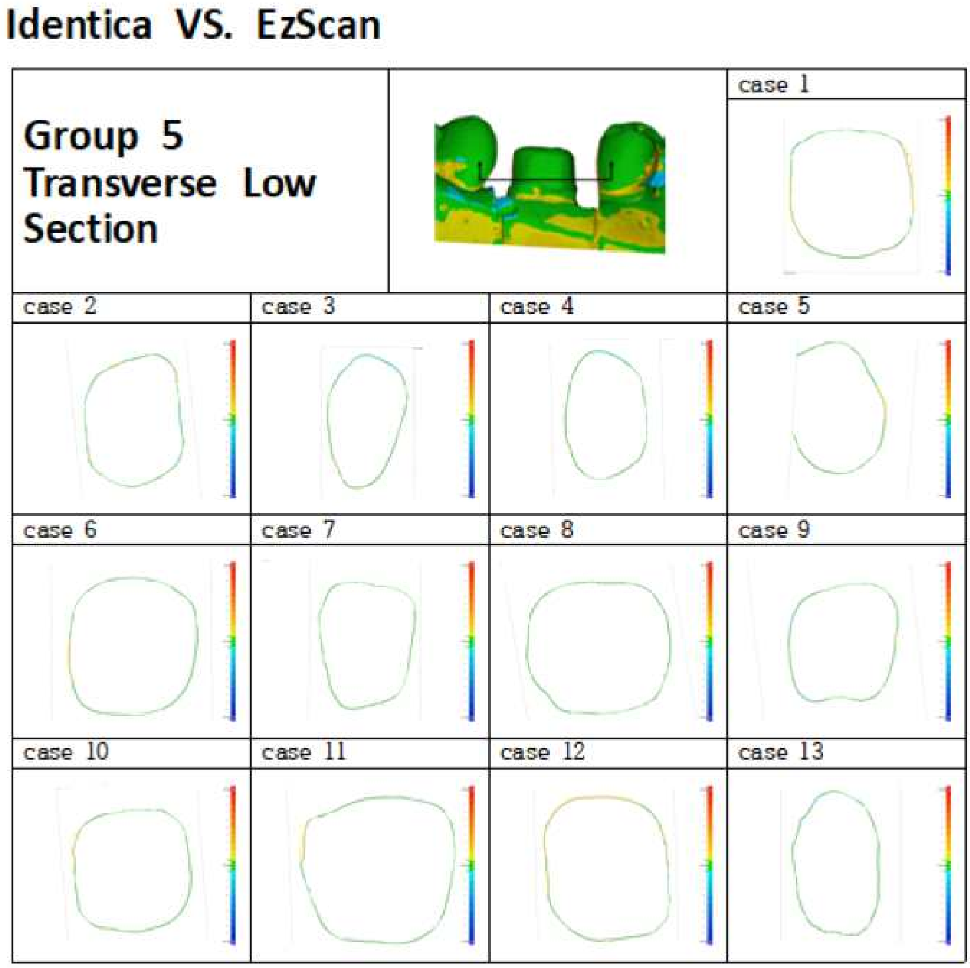

Figure 11. Result of two-dimensional analysis in Identica vs. EzScan at transverse low section. Yellow lines indicate external deviations and cyan lines indicate internal deviations.

The mean negative deviation (internal; −), mean positive deviation (external; +), and RMS values of Trios 3 group 1 were −0.014 ± 0.008, 0.018 ± 0.017, and 0.026 ± 0.025 mm, respectively. The mean deviation and RMS values for group 2 were −0.104 ± 0.144, 0.039 ± 0.034 and 0.083 ± 0.074 mm, respectively. The mean deviations and RMS values for group 3 were −0.015 ± 0.008, 0.022 ± 0.013 and 0.030 ± 0.023 mm, respectively. The mean deviations and RMS values of group 4 were −0.022 ± 0.024, 0.019 ± 0.010, 0.037 ± 0.038 mm, The mean deviations and RMS values of group 5 were −0.018 ± 0.011, 0.021 ± 0.011, and 0.033 ± 0.025 mm, respectively.of EzScan group 1 were −0.041 ± 0.013, 0.052 ± 0.016 and 0.057 ± 0.014 mm, respectively. The mean deviations and RMS values for EzScan group 2 were −0.058 ± 0.024, 0.069 ± 0.043, and 0.094 ± 0.052 mm, respectively. The mean deviations and RMS values of group 3 were −0.045 ± 0.022, 0.039 ± 0.032 and 0.054 ± 0.022 mm, respectively. The mean deviations and RMS value of group 4 were −0.029 ± 0.01, 0.041 ± 0.023, 0.057 ± 0.014 mm, respectively. The mean deviation and RMS values of group 5 were −0.030 ± 0.012, 0.044 ± 0.015, and 0.055 ± 0.018 mm, respectively (Table 3).

Table 3 Results of two-dimensional analysis for 2 intraoral scanners (Trios 3, EzScan) vs. Identica at 5 cross sections (BL, MD, TH, TM, TL) expressed with RMS, mean positive deviation, and mean negative deviation values. Asterisk indicates statistical significance ($p<0.05$)

Accuracy Results (2D)	Location	Identica (extraoral) vs. Trios (extraoral)	Identica (extraoral) vs. Ezscan (extraoral)
Root Mean Square	Buccal-Lingual	0.026 ± 0.025	0.057 ± 0.014 *
	Mesial-Distal	0.083 ± 0.074	0.094 ± 0.052
	Transverse-high	0.030 ± 0.023	0.054 ± 0.022 *
	Transverse-middle	0.037 ± 0.038	0.057 ± 0.014
	Transverse-low	0.033 ± 0.025	0.055 ± 0.018 *
Mean positive deviation	Buccal-Lingual	0.018 ± 0.017	0.052 ± 0.016 *
	Mesial-Distal	0.039 ± 0.034	0.069 ± 0.043 *
	Transverse-high	0.022 ± 0.013	0.039 ± 0.032
	Transverse-middle	0.019 ± 0.010	0.041 ± 0.023 *
	Transverse-low	0.021 ± 0.011	0.044 ± 0.015 *
Mean negative deviation	Buccal-Lingual	- 0.014 ± 0.008	- 0.041 ± 0.013 *
	Mesial-Distal	- 0.104 ± 0.144	- 0.058 ± 0.024
	Transverse-high	- 0.015 ± 0.008	- 0.045 ± 0.022 *
	Transverse-middle	- 0.022 ± 0.024	- 0.029 ± 0.011
	Transverse-low	- 0.018 ± 0.011	- 0.030 ± 0.012 *
* P < 0.05, Mean ± SD			

Comparison of accuracy of the two scanners displayed statistically meaningful differences in group 1 (buccal-lingual), 3 (transverse-high), and 5 (transverse-low). Trios 3 exhibited better reproducibility than EzScan in all three groups. At buccal-lingual section, Trios 3 was more accurate than EzScan. At mesial-distal section, both Trios 3 and EzScan exhibited high deviations. RMS and mean deviation values of groups 2 (mesial-distal) exhibited no statistically meaningful difference between Trios 3 and EzScan. No significant differences in group 2 may be interpreted as scanner's inability to access certain areas, or with depth made scanned images more susceptible to imprecisions. RMS and mean negative deviation of group 4 (transverse-middle) values were not statistically significant. It can be speculated that both scanners reproduce better scan images in smooth surfaces and poor images in irregular segments (edge, margin). Comparatively, Trios 3 was superior in reproducing irregular surfaces in single-tooth abutment scan.

For second part of the study, accuracy at different cross-sections was compared for each scanner. Buccal-lingual (group 1) vs. mesial-distal (group 2) of each scanners, and three transverse groups (group 3, 4, 5) of each scanners were analyzed for accuracy comparison. In vertical cross sections (BL vs. MD) of Trios 3, p-values of mean negative deviation, mean positive deviation, and RMS were 0.034, 0.058, 0.022, respectively. For transverse cross sections (TH vs. TM vs. TL) of Trios 3, p-values of mean negative deviation, mean positive deviation, and RMS were 0.482, 0.831, 0.732, respectively. For comparison between vertical cross sections (BL vs.

MD) of EzScan, p-values of mean negative deviation, mean positive deviation, and RMS were 0.028, 0.181, 0.022, respectively. For transverse cross sections (TH vs. TM vs. TL) of EzScan, *p*-values of mean negative deviation, mean positive deviation, and RMS were 0.586, 0.867, 0.7388, respectively (Table 4).

Table 4 Results of two-dimensional analysis for accuracy at BL vs. MD and TH vs. TM vs. TL for each intraoral scanner (Trios 3, EzScan) expressed with RMS, mean positive deviation, and mean negative deviation values. Asterisk indicates statistical significance ($p<0.05$).

Accuracy Results (2D)	Trios 3 (Extraoral)	EzScan (Extraoral)
Root Mean Square	BL vs. MD(t-test)	
	p = 0.022	p = 0.022*
	TH vs TM vs TL (ANOVA)	
	p = 0.732	p = 0.788
Mean positive deviation	BL vs. MD(t-test)	
	p = 0.058	p = 0.181
	TH vs. TM vs. TL (ANOVA)	
	p = 0.831	p = 0.867
Mean negative deviation	BL vs. MD(t-test)	
	p = 0.034	p = 0.028*
	TH vs. TM vs. TL (ANOVA)	
	p = 0.482	p = 0.586
* p < 0.05, Mean ± SD		

In comparison between the vertical cross sections, RMS and mean negative deviation values exhibited statistically significant difference while mean positive deviation value did not. Comparison of the transverse groups did not exhibit statistical significance.

Accuracy comparison of group 1 and group 2 for each scanners showed that mesial-distal sections are more prone to error than buccal-lingual section, and statistically significant errors are expressed as negative deviations for both scanners (p = 0.028, 0.034).

Ⅳ. Discussion

The aim of this study was to evaluate accuracy outcomes of two types of scanners through 2-dimensional analyses at five digital cross-sections (mesiodistal, buccolingual, high transverse, mid-transverse, low transverse) of single-tooth abutment, and to evaluate error-prone areas of single-tooth abutment within each scanner. Studies assessing the accuracy of intraoral scanners via 2-dimensional analysis method are scarce.

Most 3-dimensional analysis methods collect data of target tooth as well as surrounding soft tissue. However, this increase in data can distort accuracy of digital dental impression. Previous studies have found lower accuracy when quadrant was scanned instead of single tooth (Mehl et al. 2009). Increase in gathered data results in falsely compensated values of best-fit algorithm. Therefore, with three-dimensional analysis, evaluation of accuracy solely on tooth is difficult. In fact, 3D analysis method's failure to detect inaccuracies often lead to confirmation of digital scanners as reliable alternative to conventional impression methods. For the reason, we came up with a 2-dimensional analysis method to more precisely assess deviations of the scanners.

Both Trios 3 and EzScan featured common weakness but at different levels. Within the finite boundaries of this study, Trios 3 was generally better at generating an accurate digital copy than EzScan. In buccal-lingual cross-section, Trios 3 showed statistically significant superiority, indicating Trios 3 performs with better accuracy on surfaces that are easily accessible. In mesial-distal cross-section, both scanners performed poorly. There was no significant difference between the two scanners, which could be interpreted as intraoral dental scanner's inherent imperfection to obtain data in deep and narrow areas (Fig. 12).

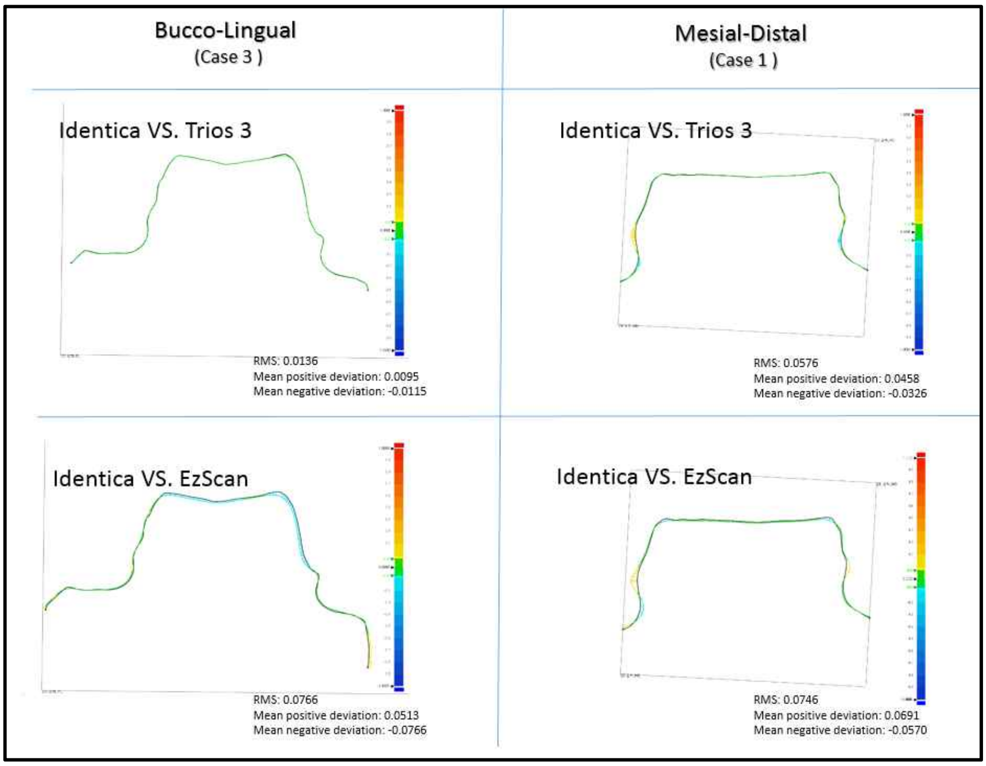

Figure 12. Comparison of Bucco-lingual section and Mesial-distal section in cases with pronounced error.

Even within transverse cross-sections, different levels of deviations were observed. In the highest and lowest transverse cross-sections, both intraoral scanners performed with fluctuating accuracies, while no significant imprecisions were observed at mid-transverse cross-section. Trios 3 demonstrated comparatively less errors than EzScan, nevertheless (Fig. 13).

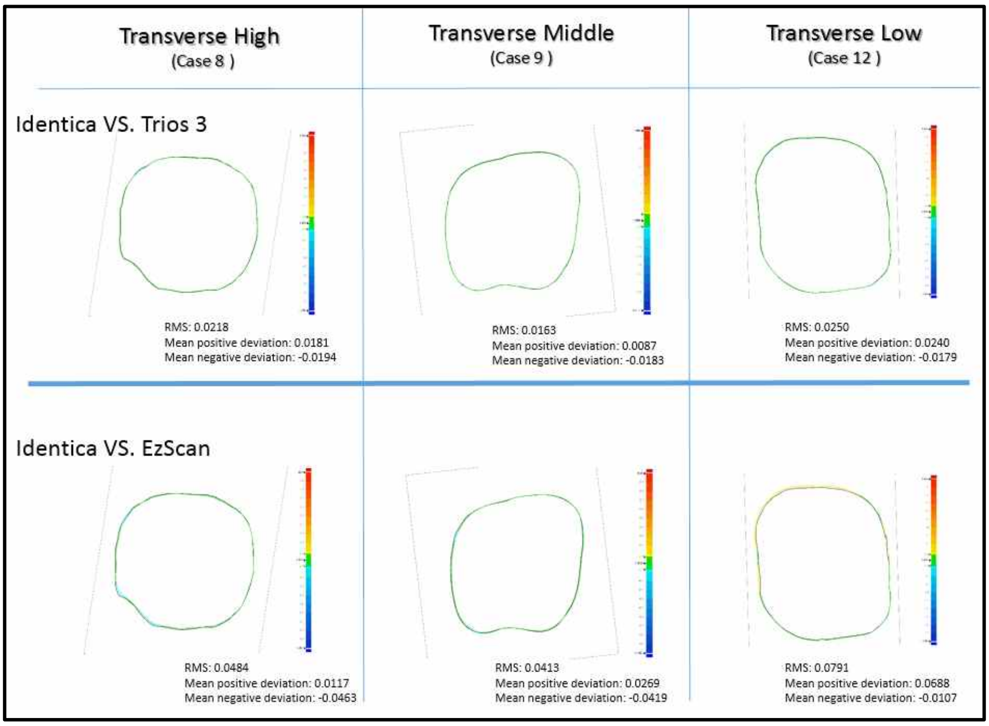

Figure 13. Comparison of Transverse high section, Transverse middle, and Transverse low section in extracted study cases with pronounced error.

The present study was designed not only to compare the reliability of the intraoral scanners but also to determine error-susceptible surfaces of each scanners. Accuracy measurements of the two scanners revealed that Trios 3 executed more accurately than EzScan in comparatively accessible sections such as buccal and lingual surfaces. In proximal areas where access is harder, however, comparative deviations were commonly observed in both intraoral scan systems. Increase of deviations was noticeable in both scanners especially where bumps or sharp angles existed. This consistency could also be found in transverse sections; sharp or roughly prepped surfaces from coronal views revealed higher deviation for both scanners. Steep axial walls showed consistent deviations in all transverse cross-sections (Fig. 14).

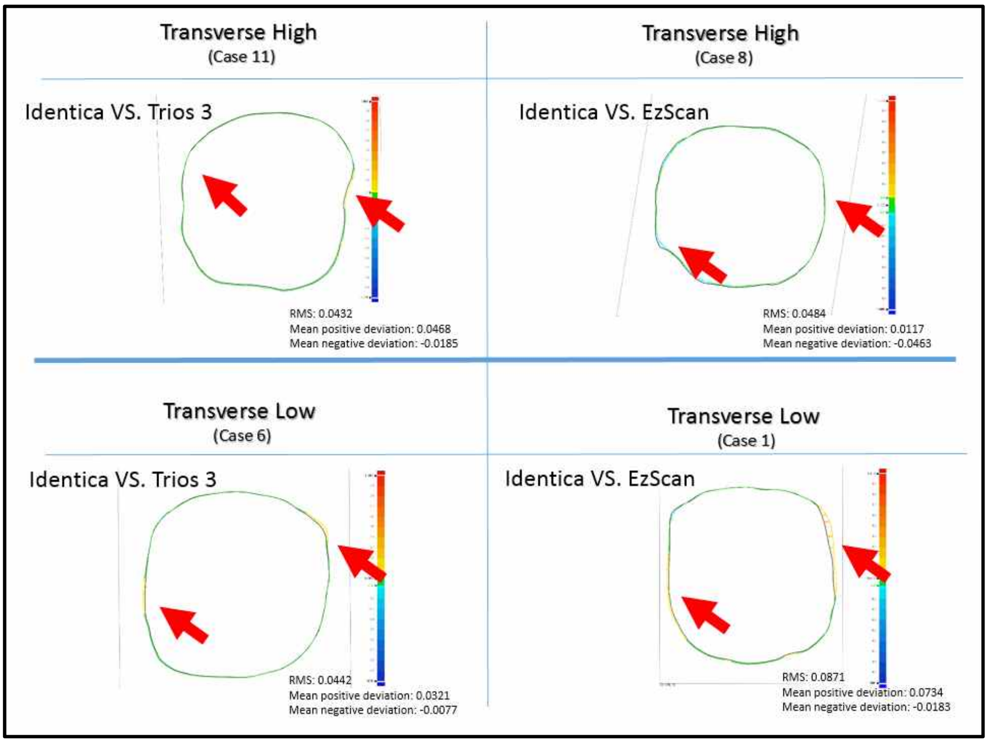

Figure 14. Sharp edges and rough areas on prepped surfaces showed high deviation errors. Red arrows indicate pronounced errors.

Results and analysis of present study lead to the common conclusion that intraoral scanner performance is highly influenced by 1) the type of scanner used and 2) structural components of the tooth involved. Similar conclusions have been derived in a number of studies regarding the importance of tooth geometry.

Yang et al. evaluated digital impressions of single crown attained with three digital scanner systems (Yang et al. 2015). Margins and distal surfaces showed greater deviations, especially in narrow or angular areas such as interproximal surfaces. The study reported that fallacies of digital impression increase when prominent angle bigger than 60° exist between scanner and the perpendicular of target surface. DeLong et al. also reported similar phenomenon. Digitization performance that excelled in smaller surface angles suddenly dropped once the angle was raised to 60° (DeLong et al. 2001). These speculations were verified in the present study as well; prominent imprecisions were detected in scanning proximal areas above and below the contact area when evaluated from vertical and transverse cross-sections. In distal areas of proximal surfaces, scanning was especially difficult because scanner wand could not construct appropriate angle against the target surface while approaching from the anterior.

Flügge et al. analyzed precision of intraoral and extraoral digital impressions in the maxilla and the mandible (Flügge et al. 2013). Full-arch scans of the maxilla and the mandible were sequentially performed intraorally and extraorally, after which analysis for inaccuracy proceeded. Intraoral and extraoral digital dental impressions revealed similar patterns of inaccuracies in both the maxilla and mandible. Intraoral results showed higher deviations than extraoral results, possibly due to uncontrollable patient factors.

Palatal borders and interdental spaces exhibited deviations above average. Facial surfaces of anterior teeth, with steep angles, and molars with undercuts and sharp angles also showed pronounced imprecisions. High deviation values in these areas could be presumed to have occurred from failed attainment of constructive information at rugged edges and angles.

As for labial surfaces of anterior teeth, pronounced imprecision seem to have risen from steep angles. Therefore, additional scans from several directions are required for steep areas of anterior labial surface. In the molar areas, virtual images reproduced were more unreliable. Areas that failed to accurately reproduce may be caused by complex geometry of molars, with many angled surfaces, and undercuts of the adjacent teeth. In the present study, there was also a varying degree of deviation among the single-tooth casts. In transverse cross-sections, it was seen that teeth with deeper curves displayed the inferior precision than smoothly round teeth even though identical scanning protocols were applied.

Flügge et al. also concluded that imprecision in digital impression is dominated by tooth shape. These results were consistent with the present study results in that areas of strong angular changes resulted in higher deviation values. Flügge et al. additionally reported imprecision differences between the maxilla and mandible. This information was not dealt in the present study even though similar number of tooth from both the maxilla and the mandible was examined during analysis. Although minimal difference was noted by Flügge et al., it would be interesting to advance the present study by categorizing inaccuracies to see if new insights could be offered.

In the present study, directionality of deviations was indicated. Interestingly, obvious curvatures in tooth geometry and protruding margins in interproximal areas commonly showed positive deviation whereas undercut areas showed negative deviation. Although individual differences exist, positive deviations could most easily be observed at mesial/distal corners in transverse-high cross-sections, and negative deviations could easily be observed in mid-transverse areas from mesial-distal cross-sections. Rudolph et al. yielded similar conclusions in his study. Molar areas with sharp angular changes were more prone to negative deviation while steep areas including mesial/distal corners showed strong positive deviation. However, some discordant results were presented in analysis of canine. Present study could not verify such results since the present study focused on posterior teeth. Rudolph et al concluded that tooth shape was as decisive as type of scanner in data acquisition (Rudolph et al. 2006). Therefore, different strategies may be considered depending on the tooth geometry despite identical procedures.

This study was performed extraorally using stone casts. Extraoral digital impressions usually perform with higher precision than intraoral ones. Had this study tested for accuracy intraorally, results may have displayed greater fluctuations even with identical scanning protocols due to patient factors such as saliva and tongue movements. It can easily be presumed that areas that exhibited high imprecisions due to lack of space will show higher deviations in limited intraoral space (Flügge et al. 2013). Therefore, careful approach of the scanners is needed especially in interdental areas.

Most intraoral scanners struggle to achieve acceptable level of accuracy in proximal areas. According to scanning protocols, a certain amount of image data must fundamentally be acquired for an acceptable depiction of a tooth. However, it is difficult to acquire adequate amount of images in these regions because optimal angle of the scanner is constrained by intraoral space and surrounding anatomy. The simplest way to overcome the spatial restriction is to scan the region multiple times with different angular views. Repetition with varying angle tilts can contribute more measured points in regions with strong curvature or rough angles, yielding more information. Increased constructive data will generate a more precise virtual model independent of inherent auto-correction by scan software. Meticulous depiction of the proximal corners will essentially lead to an overall increase in quality of design. Furthermore, increased image data in the otherwise troublesome surfaces would make following mid-treatment modifications on virtual model more effective, yielding improved integrity of the final prosthetic rehabilitation (Mehl et al. 2009).

Conventional impression method is not perfect. Although errors are inevitable, compensation to an acceptable level during other production process results in a satiable prosthetic rehabilitation. Error may also arise during digital dental impression. However, the difference is that errors during digital impression is not compensated enough. Rather, errors in digital workflow have a cumulative effect. Internal fit and marginal gaps are common problems of dental restorations fabricated through digital production process (Carbajal et al. 2017). For this reason, clinicians are inevitably more sensitive to errors during digital data acquisition. Although foremost solution to this problem will be manufacture of more reliable intraoral scanners, it is up to clinicians to explore techniques to overcome visual interferences during digital scanning.

V. Conclusion

Limited to the boundaries of present study, following conclusions could be drawn:

1. Two-dimensional analysis is more insightful than three-dimensional analysis on single-tooth abutment area.
2. Appropriate approachability, depth, reflection angles leading to complete attainment of data is important of scanners is important as much as accuracy of the scanners. That is, efforts must be made to avoid dead space, especially in proximal areas where errors are frequently made.
3. In tooth preparation for digital impression taking, it is important to extend smooth planes without sharp edges. Sharp edges result in high deviation during intraoral scanning.

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단일치아 지대주에서 2종의 구강스캐너의 2차원분석에 따른 정확도 비교

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맹 지 연

1. 목 적

현재 2 차원 분석 방법으로 구강 내 스캐너의 정확성을 평가하는 연구는 거의 없다. 이 연구의 목적은 금관제작을 위해 삭제한 단일치아 지대주에서 획득한 디지털 모형을 이용하여 협설측 절단면, 근원심 절단면과 횡단면으로 절단하여, 2 종의 구강스캐너간의 정확도와 각 구강스캐너별 정확도를 2 차원적인 방법으로 비교분석하는 것이다.

2. 방 법

서울대학교 치과병원에서 2017년 12월 7일부터 2018년 8월 22일까지 시행된 임상시험(IRB No. CDE17004)의 13명의 연구대상자 (남: 6명, 여:7명/ 평균 나이: 53.92 (± 10.43))에서 종래형 인상으로 획득한 13개의

단일치아삭제모형을 대상으로 하였다. 석고모형을 모델스캐너인 Identica Hybrid® (Medit Co, Seoul, Korea)로 디지털스캔하여 대조군으로 하고, 두 종류의 구강스캐너(Ezscan®: Vatech, Hwaseong, Korea / Trios 3®: 3 Shape, Copenhagen, Denmark)로 획득한 디지털 인상을 실험군으로 시행하였다.

Geomagic® Control X™(3D Systems, Rock hill, USA)의 Best Fit Alignment 기능을 이용해 3차원적으로 중첩 된 데이터를 1군: 협설측 절단면(BL), 2군: 근원심 절단면(MD), 3군: 횡단면상부(TH), 4군: 횡단면 중앙(TM), 5군: 횡단면하부(TL)의 5개의 군으로 나누어서 2차원적인 변위 차이를 분석하였다. 결과 값은 대조군 데이터 대비 실험 데이터의 차이가 나는 평균편차 (내부;-, 외부;+)과 RMS의 평균과 표준편차로 나타내었다.

5 개의 횡단면 그룹에서 2 개의 스캐너 사이의 정확도 비교는 paired t-test를 사용하였다. 각 스캐너에 대한 BL과 MD의 비교는 t- test를, TH, TM 및 TL의 비교는 one-way ANOVA test를 사용하였다. Post-hoc test는 Student-Newman-Keuls 방법을 사용 하였다. 모든 변수는 평균과 표준 편차로 나타내었으며 p <0.05는 통계적으로 유의하다고 간주되었다.

3. 결 과

5 개의 횡단면에서 2 개의 구강 내 스캐너에 대한 2 차원 분석의 비교는 1, 3, 5 군에서 통계적으로 의미 있는 차이를 보였다. Trios 3은 buccal-lingual 면에서 EzScan보다 우수한 결과를 보였지만, mesial-distal 면에서 Trios 3과 EzScan 모두 높은 편차의 오류를 나타냈다. 반면 2, 4군에서의 차이는 통계적으로 유의하지 않았으며, 다만 transverse-middle 면에서 Trios 3의 정확도는 EzScan보다 뛰어났다.

구강 내 스캐너에서 BL vs. MD 비교는 RMS와 평균 음성 편차 값에서 통계적으로 유의 한 차이를 보였으나 평균 양성 편차 값은 통계적으로 유의하지 않았다. 결과는 mesial-distal부가 buccal-lingual부 보다

스캔 오류에 취약하고, 통계적으로 유의 한 음성 편차 값은 두 스캐너에서 모두 음의 편차로 오류가 나타남을 보여준다. 횡단 그룹은 통계적으로 유의 한 차이를 보이지 않았다.

4. 결 론

단일치아 지대주에서의 스캐너 상 오차 분석에 있어서 2차원적 분석은 3차원적 분석에 비하여 더 유의미하다. 구강스캐너의 촬영 시 접근도가 떨어지는 근원심 부위와 프렙 시 평탄하지 않은 부위와 뾰족한 엣지 부위에서 높은 편차의 오차를 나타낸다.

Key Words : 구강스캐너, 정확도, 이차원분석, 내·외부평균편차, RMS

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