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A novel method to analyze three-dimensional accuracy of complete-arch dental impression

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A novel method to analyze three-dimensional accuracy of complete-arch dental impression

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감사의 글

부족한 저를 논문이 쓰이고 완성되는 데 있어 많은 가르침과 조언을 주시고 지식을 전달해 주신 김선재 지도 교수님께 깊은 감사의 말씀을 전합니다. 연구자로서의 자세를 알려주시고 바쁘신 와중에서 매번 논문 작성에 있어서도 많은 도움을 주셔서 감사합니다. 항상 열정과 지성을 보여주신 교수님을 진심으로 존경합니다. 심사 과정에서 많은 조언을 주시고 첨언을 해주신 심준성 교수님, 실험의 설계 및 평가과정에서 격려와 도움을 주신 장민호 교수님께 진심으로 감사드립니다.

수련기간 동안 치과보철과에서 무한한 가르침을 주시고 경험을 쌓게 해주신 장재승 교수님, 수련의 생활에 많은 도움을 주신 김경록 선생님께 감사의 말씀을 전합니다. 또한 실험과정에서 여러 도움을 준 친구이자 선배인 장근원 선생님께도 감사의 말씀을 전합니다. 더불어 힘들고 어려울 때에도 언제나 함께해준 동기 최승희 선생, 의국 선배님, 후배님들께도 고맙다는 말을 전하고 싶습니다. 논문 작성 중에 통계 분석 및 처리에 많은 도움을 주신 김시내 선생님께도 감사드립니다.

마지막으로 언제 어디서나 나의 물심양면으로 힘이 되어준 아버지, 어머니, 많이 챙겨주지 못한 여동생과 남동생과 함께 이 기쁨을 나누고 싶습니다.

2018년 6월

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Different methods were used to evaluate the accuracy of the dental impression, but each method had some limitations. The purpose of the current study was to present a new method to evaluate the three-dimensional accuracy of different impression techniques including intraoral digital scanning. Additionally, the accuracies of conventional impression and digital impression using intraoral scanner were compared by using this method.

The master model was fabricated using fourteen milled polyetheretherketone cylinders (Diameter: 5mm, Length: 15mm) and maxillary acrylic model. Each cylinder was positioned and named as the corresponding tooth number. Twenty-five definitive casts were fabricated using conventional impressions of the master model. Also, twenty-five intraoral digital scans of the master model were performed to reconstruct twenty-five digital models. Two different methods were used to calculate the three-dimensional coordinate of each cylinder's centroid. For the master model and the definitive casts, a computed coordinate measuring machine (Micura, Zeiss, Germany) was used to probe the centroid of each cylinder. An inspection software (Geomagic Control X, 3D systems, USA) was used to probe the centroids of digital models. A three-dimensional part coordinate system was defined to evaluate the amount of three-dimensional displacement of each centroid coordinates. The ΔD value, represented by the amount of overall three-dimensional displacement was evaluated.

Trueness and precision were evaluated and analyzed. For trueness, in most of the tooth positions showed that conventional impression method was significantly more accurate than digital impression using an intraoral scanner (p <0.05). Linear mixed models showed that conventional impression method was significantly more accurate than digital impression using an intraoral scanner (p <0.05) in x, y, z and ΔD variables. For precision, the conventional impression method showed consistently lower values than digital impression using an intraoral scanner at every tooth position.

In the current study, a new method was presented and used to evaluate the accuracy of

full-arch impressions. By using this new method, a three-dimensional evaluation of full-arch impression accuracy was possible. Both trueness and precision, conventional impression method was more accurate than digital impression using an intraoral scanner.

Keywords: Accuracy, Conventional impression, Digital impression, Full-arch

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I. Introduction

An accurate impression is one of the crucial factors for the long-term success of prosthesis.[1, 2] Different impression materials and impression techniques have been used to make the accurate reproduction of intraoral environment.

Due to the remarkable development of dental computer-aided design and computer-aided manufacturing (CAD-CAM) technology, many kinds of intraoral scanners with different technologies were introduced and used in clinical practice.[3][4][5, 6] Contrast to the conventional impression, intraoral scanners can make impressions without impression materials or trays. [7][8] Instead, still or video images of the intraoral environment are captured, then the images are reconstructed to build a digital model. Once a digital model is built, the model can be easily transferred to dental laboratories to discuss and fabricate the final prosthesis. Due to the absence of a physical model, digital impressions can exclude the errors resulted from the expansion of modeling stone, shrinkage or distortion of impression materials.[9] According to previous studies, patients feel more comfortable when making a digital impression using intraoral scanners than conventional impression method. [10][11][12-14]

Recently, many studies evaluated the accuracy of intraoral scanners and compared the degrees of accuracy with those of conventional impression using impression materials and modeling stone.

Boeddinghaus et al. compared the accuracy of three different intraoral scanners with the accuracy of conventional impression, and concluded that the accuracy of intraoral scanners was comparable to the accuracy of conventional impression.[15] Güth et al. compared the accuracy of full arch intraoral digital scan to conventional impression and concluded that digital impression using an intraoral scanner was as accurate as conventional impression or showed even higher accuracy than conventional impression.[16] Tomita et al. also evaluated the accuracy of an intraoral scanner and conventional impression in a full arch model, and reported that intraoral scanners showed significantly higher accuracy than conventional impression.[17] On the contrary, Cho et al. compared the accuracy and reproducibility of a digital impression using intraoral scanner with a conventional impression technique, and reported that the conventional impression was more accurate than the digital impression using an intraoral scanner.[18] A recent review also concluded that conventional impression technique was more accurate than digital impression using intraoral scanners for full-arch impression.[19] Kuhr et al. and Su et al. concluded that accuracy of intraoral scanner depended on span of arch.[20, 21] In terms of single tooth impression, many studies demonstrated that accuracy of intraoral scanner was equivalent or even higher than conventional impression. However, in terms of long span or full arch impression, accuracy of digital impression using intraoral scanner and conventional impression was remained controversial.[16, 22-26]

Different methods were used to evaluate the accuracy of definitive casts fabricated by conventional impression. Conventional impression method involved definitive casts (physical model), therefore, most former studies evaluated deviation between master model and definitive casts. These studies used visual inspection of misfit between definitive casts and prostheses with naked eye, measuring displacement of abutment tooth with dial gauge or measuring the displacing amount of specific markers with vernier caliper.[27-30] Contrast to the evaluation of the accuracy of conventional impression, digital impression using intraoral scanner only fabricate the digital models, therefore, different evaluation methods were tried to evaluate the accuracy of intraoral scanners.

Most of the previous studies used “best fit alignment” to compare the accuracy of digital impressions. However, this method inherently included superimposition errors, which is commonly over-exaggerated or sometimes underestimated in complete-arch models. Within one quadrant, results of superimposition process were acceptable, however, in case of full arch impression, errors were accumulated so the results may not be accurate. [16] To compare the accuracy of intraoral scanners and conventional impression by superimposition, master and definitive model must be converted to the digital model and this process increases errors. Moreover, best-fit alignment method would mask distortions by moving the distorted models in the most optimal position to the master model.[20] On the other hand, Güth et al. evaluated full arch scans excluding superimposition technique.[16] But, this study only evaluated deviation of a bar located between molars so the deviation of each tooth was hard to evaluate. Despite these drawbacks, former studies had no choice but to use superimposition technique to compare the accuracy of full arch composed of natural teeth because of irregular tooth shape.

In the current study, basic geometry was used using typical cylinders instead of the natural tooth. A three-dimensional coordinate system was introduced to measure distortion of conventional and digital impression techniques to exclude the inherent errors while superimposing digital models to compare the amount of distortion. Master model and definitive casts were measured using a physical probe of a CMM and digital models were measured using the virtual probe of the geometric software (Geomagic Control X, 3D systems, USA) by introducing metrology. Further, errors while converting the master and definitive casts to digital models were also excluded by using this method.

In the current study, the metrological concept was introduced to evaluate the accuracy of complete arch impression. All maxillary teeth were replaced with a basic geometric configuration, which is a cylinder, therefore, the accuracy of complete arch impression was evaluated by the three-dimensional coordinate position of each cylinder's centroid. The master model and definitive casts were measured using a physical probe of a CMM and digital models were measured using a digital probe of the geometric inspection software (Geomagic Control X, 3D systems, USA). Further, errors while converting the master model and definitive casts to digital models were also excluded by using this method.

The purpose of the current study was to present a new method to evaluate the three-dimensional accuracy of different impression techniques including intraoral digital scanning. Additionally, the accuracies of conventional impression and intraoral scanner were compared by using this method. The null hypothesis tested was that no significant difference was noted in the accuracy between conventional impression and intraoral digital scan in full-arch impression by using this new analyzing method.

II. Material and methods

1. Fabrication of models

1) Fabrication of the master model

Fourteen polyetheretherketone (PEEK; US Korea, Korea) cylinders (Diameter: 5mm, Length: 15mm) were milled using an industrial computer numerically controlled (CNC) lathe. The industrial CNC lathe provided tolerance of less than 2㎛. After all resin teeth were removed from an acrylic maxillary model (D85DP-500B, Nissin dental products Inc., Japan), utility wax was filled adequately at empty sites. An impression was made to duplicate the maxillary model using high viscosity (Exafine putty type, GC, Japan) and low viscosity polyvinyl siloxane impression material (Aquasil XLV, DentsplySirona, USA) in a metal stock tray. After complete polymerization of impression materials, the tray was removed from the model. Epoxy resin (Polyurock, Cendres Metaux, Switzerland) was mixed under manufacturer’s instructions, poured into the impression, and waited to 10 hours to polymerization. The epoxy resin model was removed from the impression, then a hole (diameter 5.5mm, length 10mm) was made at each tooth position using a carbide bur (HP701-012, Komet, Germany) to insert the PEEK cylinders. The PEEK cylinders were fixed using self-polymerization acrylic resin (Jet, Lang Dental Mfg, USA) with 5mm was extruded from the crest. Each cylinder was assigned as the corresponding tooth number with the letter of C (for example; #17C). In a pilot study, an intraoral scanner failed to differentiate each cylinder due to the identical configuration of PEEK cylinders. Therefore, various irregular patterns were engraved around PEEK cylinders (Fig. 1).

Figure. 1 Master model. Various irregular patterns were engraved around the PEEK cylinders to distinguish one cylinder to others.

2) Fabrication of definitive casts using conventional impression method (Group CI)

Conventional impressions of the master model were made using a low viscosity polyvinylsiloxane impression material (Aquasil XLV) and a custom tray (Fastray, Bosworth, USA). Tray adhesive (VPS tray adhesive, Kerr, Japan) was applied and dried 5 minutes before the impression. The tray was positioned for 10 minutes before removal from the master model. Type IV stone (MG Crystal Rock, Maruishi Gypsum Co, Japan) was mixed and poured into the impression following the manufacturer's instructions. The definitive casts were allowed to set for 1 hour before removal. The casts were trimmed for the convenience of measurement. A pilot study showed that estimated sample size was more than 23 with $\alpha = 0.05$ and power of 95%. The procedure was repeated to fabricate twenty-five definitive casts. (Fig. 2).

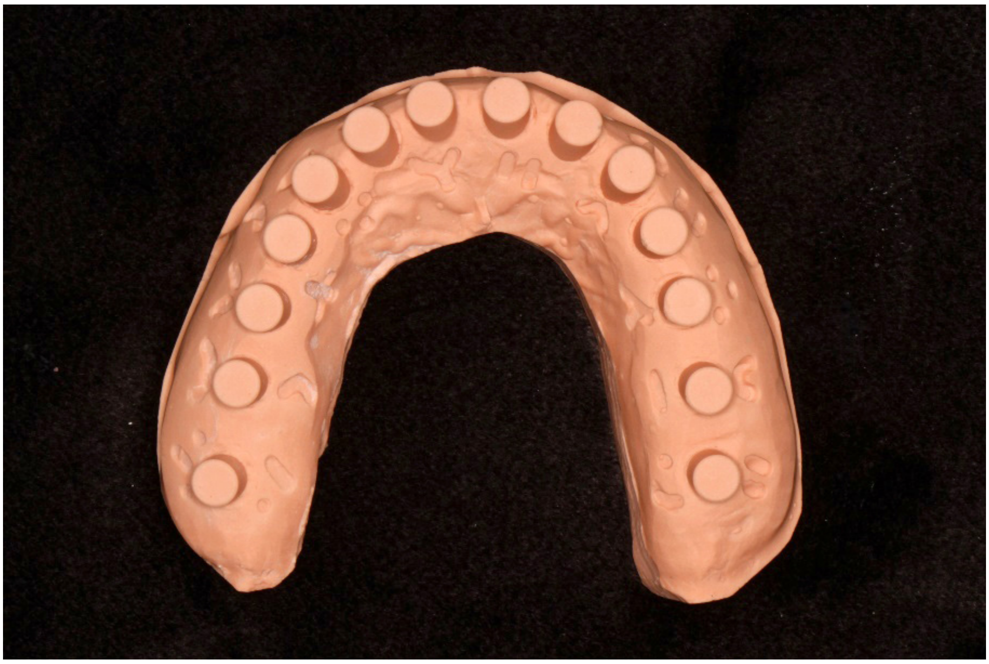

Figure 2. Definitive cast.

3) Fabrication of digital models using an intraoral scanner (Group IOS)

An intraoral scanner (Trios 3, 3shape, USA) was used to fabricate the digital models. A calibration procedure was preceded before each scan procedure. A digital scan was made followed by manufacturer's instructions without any scanning spray application. Scanning was started from #27C to #17C and saved as a standard tessellation language (STL) file format. Twenty-five digital models were fabricated using the same method.

2. Measurement

Two different methods were used to calculate the three-dimensional coordinates of each cylinder's centroid (Fig. 3).

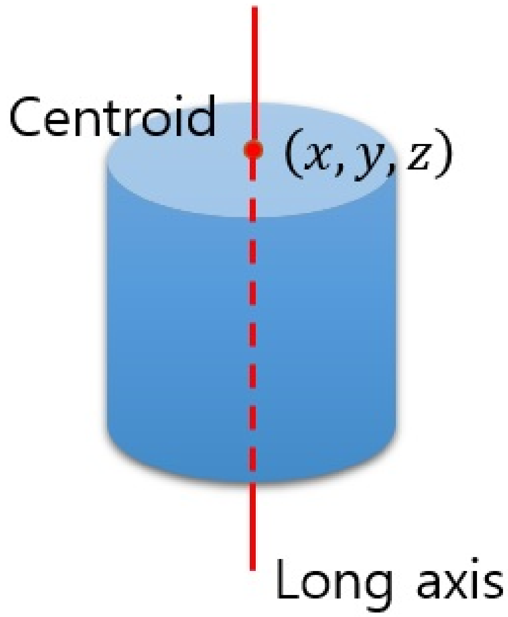

Figure 3. Three-dimensional coordinate definition of the centroid.

For the physical models, which were the master model and the definitive casts fabricated by conventional impressions, a computerized coordinate measuring machine (CMM; Micura, Zeiss, Germany) was used to probe each cylinder, then, the centroid of each cylinder was computed using a geometric software (Calypso, Zeiss, Germany) (Fig. 4).

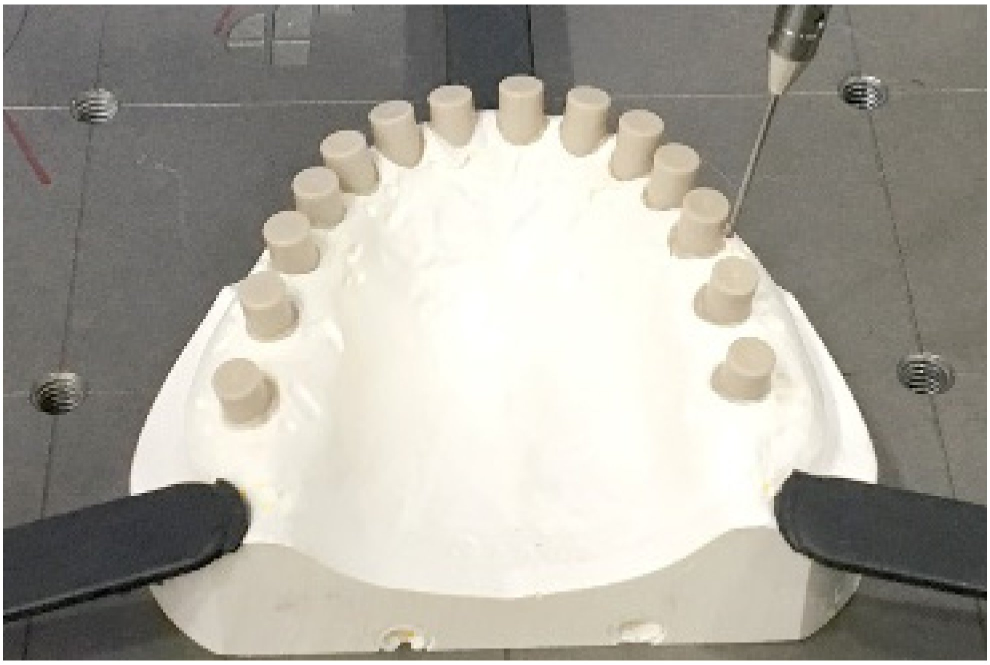

Figure 4. Measurement of the master model using a CMM.

According to the manufacturer, the accuracy of the repeatability of the CMM was about 0.7㎛. For the digital models fabricated by an intraoral scanner, an inspection software (Geomagic Control X, 3D systems, USA) with a digital probe was used to compute the centroid of each cylinder (Fig. 5).

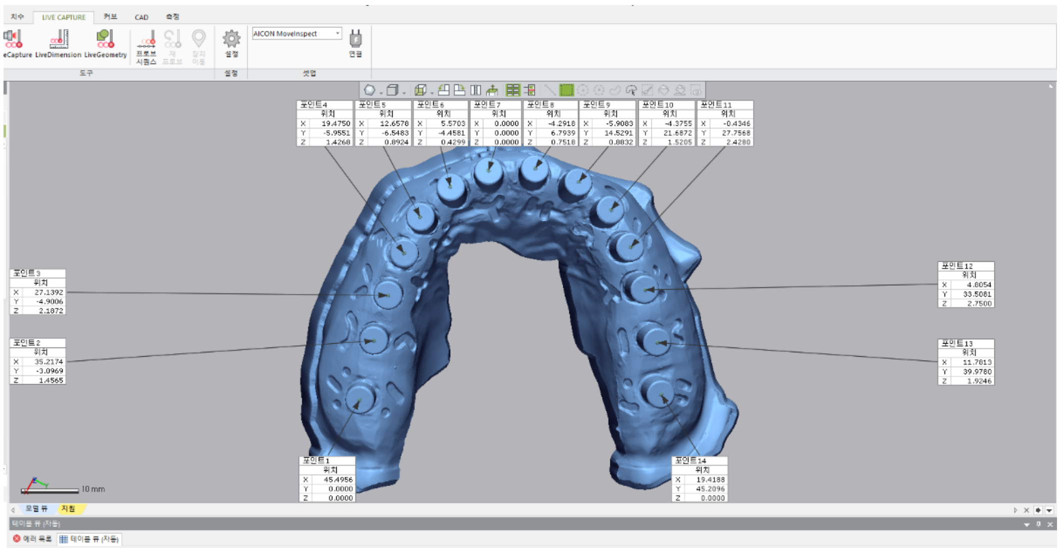

Figure 5. Three-dimensional coordinate measurement of the digital model using an intraoral scanner

A three-dimensional part coordinate system was defined as follows. Centroid of #11C was defined as the origin (0, 0, 0). A line connecting the centroids of #11C and #17C was assigned as the X-axis. A plane consisted of three points, which were centroids of #17C, #11C, #27C was assigned as the XY plane. (Fig. 6). The $(x,\ y,\ z)$ coordinate of each cylinder was re-computed based on the part coordinate system defined.

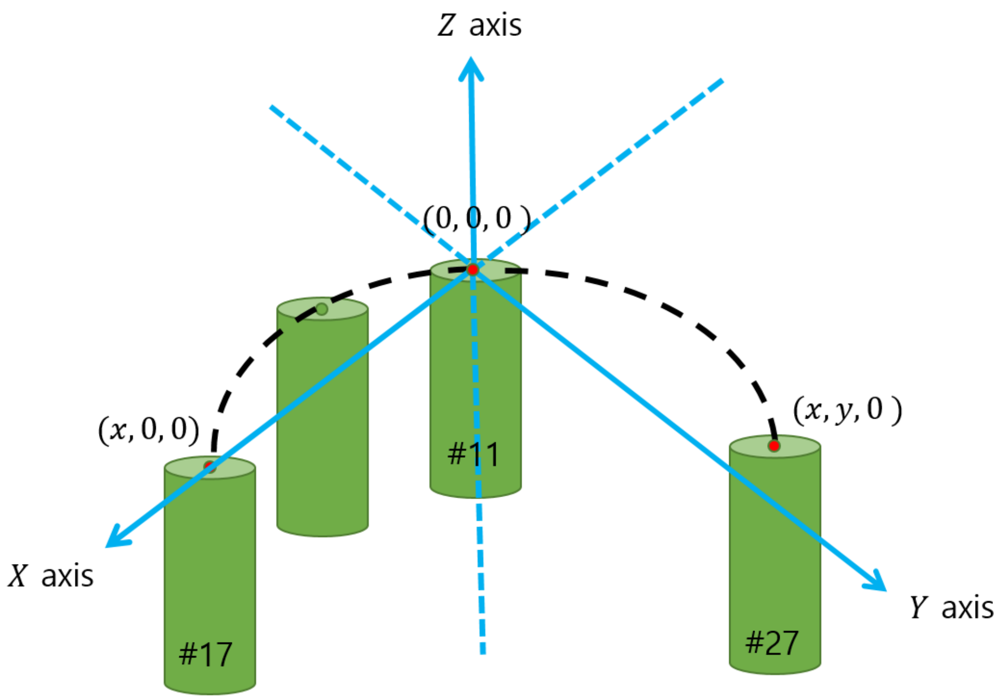

Figure 6. A three-dimensional part coordinate system used in the current study. Centroid of #11 was defined as the origin $(0, 0, 0)$. A line connecting centroids of #11C and #17C was assigned as the X-axis. A plane consisted of three points, which were centroids of #17C, #11C, #27C was assigned as the XY plane

Accuracy consists of trueness and precision.[25] In the current study, trueness was defined as the amount of linear displacement of each cylinder's centroid between the master model and test group (Group CI, Group IOS). The amount of linear displacement was represented by the amount of centroid coordinate difference in absolute values $(\Delta x,\ \Delta y,\ \Delta z)$. The amount of overall three-dimensional displacement was represented by ΔD and $D = \sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2}$ (Fig. 7).

Precision is described as the degree of closeness between repeated measurements. Precision values were calculated according to the coordinate difference between 25 specimens in the same group, therefore, each x, y, z coordinate had 300 (${}_{25}C_2$=300) values, and the absolute values were used for statistical comparison. Mean and standard deviations of difference values were calculated. For the convenience, measured values were displayed as (axis, tooth number) (i.e. X17; X-axis and #17 tooth number).

3. Statistical analysis

Statistical evaluation was performed using analysis software (Statistical Package for the Social Science Version 23, SPSS Inc., USA).

The intraclass correlation coefficient (ICC) was calculated for the reliability of repeated measurements of identical objects. Then, to analyze the trueness, absolute discrepancies between control and experimental groups, the independent two-sample t-test was applied (n=25). Lastly, a linear mixed model was applied for the general tendency. To analyze the precision, the independent two-sample t-test was applied (n=300). The level of significance was set at 5 % (p<0.05).

III. Results

1. Reliability

For reliability test, all test showed 1.000 (Table 1). According to Landis et al., the ICC (Intraclass coefficient) value was expressed from 0 to 1. As ICC value closed to 1, the data was shown to have higher reliability and ICC value between 0.81 and 1.00 interpreted as having almost perfect reliability.[31] In the current study, all measurements had significant reproducibility.

Table 1. Reliability test.

		ICC (95% CI)	*p*-value
Master model	X	1.000 (1.000-1.000)	<0.001
	Y	1.000 (1.000-1.000)	<0.001
	Z	1.000 (1.000-1.000)	<0.001
Group CI	X	1.000 (1.000-1.000)	<0.001
	Y	1.000 (1.000-1.000)	<0.001
	Z	1.000 (1.000-1.000)	<0.001
Group IOS	X	1.000 (1.000-1.000)	<0.001
	Y	1.000 (1.000-1.000)	<0.001
	Z	1.000 (1.000-1.000)	<0.001

2. Trueness

For three-dimensional coordinates of centroids discrepancies between groups (absolute value), the independent two-sample t-test was used and two groups mostly showed the significant difference (Table 2). Three-dimensional coordinates of X17, X16, X15, X14, X21, X22, X23, X24, X25, X26, X27, Y16, Y15, Y14, Y22, Y23, Y24, Y25, Z16, Z15, Z14, Z13, Z12, Z22, Z23, Z24, Z25, Z26 showed significant difference (p <0.05). With three-dimensional coordinates of X17, X16, X15, X14, Y22, Y23, Y24, and Y25, digital impression using intraoral scanner showed more accurate than conventional impression method. In contrast, with three-dimensional coordinates of X21, X22, X23, X24, X25, X26, X27, Y16, Y15, Y14, Z16, Z15, Z14, Z13, Z12, Z22, Z23, Z24, Z25 and Z26, conventional impression method showed more accurate than digital impression using an intraoral scanner. These results showed conflict with each other by tooth position. For D value, tooth position of #17, 16, 12, 21, 22, 23, 24, 25 and 26 showed significant difference (p <0.05). With D17 and D16, digital impression using intraoral scanner showed more accurate than conventional impression method. In contrast, with D12, D21, D22, D23, D24, D25 and D26, conventional impression method showed more accurate than digital impression using an intraoral scanner. With linear mixed models, calculated for the general tendency, all variables showed that conventional impression method was significantly more accurate than digital impression using an intraoral scanner (p <0.05) (Table 3).

Table 2. Trueness values (㎜). Mean discrepancies values ± standard deviation (SD) between master group and test group.

	Position	Group CI	Group IOS	*p*-value
X	17	0.086±0.024	0.054±0.027	<0.001
	16	0.068±0.018	0.039±0.022	<0.001
	15	0.047±0.016	0.028±0.016	<0.001
	14	0.032±0.013	0.023±0.015	0.033
	13	0.025±0.010	0.020±0.013	0.107
	12	0.009±0.006	0.010±0.007	0.666
	21	0.007±0.006	0.019±0.011	<0.001
	22	0.013±0.015	0.045±0.027	<0.001
	23	0.020±0.019	0.063±0.043	<0.001
	24	0.019±0.019	0.080±0.057	<0.001
	25	0.023±0.023	0.100±0.072	<0.001
	26	0.029±0.026	0.109±0.081	<0.001
	27	0.033±0.029	0.117±0.094	<0.001
	Overall	0.032±0.029	0.055±0.058	<0.001
Y	16	0.005±0.005	0.015±0.012	<0.001
	15	0.005±0.004	0.018±0.014	<0.001
	14	0.008±0.005	0.019±0.014	0.001
	13	0.011±0.005	0.015±0.012	0.106
	12	0.008±0.005	0.009±0.006	0.504
	21	0.015±0.008	0.012±0.010	0.247
	22	0.031±0.015	0.018±0.012	0.002
	23	0.045±0.015	0.022±0.017	<0.001
	24	0.057±0.015	0.039±0.017	<0.001
	25	0.071±0.017	0.058±0.025	0.036
	26	0.095±0.026	0.087±0.040	0.426
	27	0.111±0.033	0.099±0.058	0.386
	Overall	0.035±0.050	0.038±0.038	0.183

Z	16	0.004±0.004	0.012±0.009	0.001
	15	0.007±0.007	0.016±0.011	0.003
	14	0.008±0.011	0.015±0.011	0.018
	13	0.008±0.013	0.014±0.012	0.092
	12	0.005±0.010	0.012±0.010	0.015
	21	0.008±0.010	0.011±0.007	0.241
	22	0.014±0.018	0.022±0.015	0.089
	23	0.015±0.016	0.026±0.020	0.029
	24	0.012±0.011	0.030±0.021	0.001
	25	0.011±0.010	0.029±0.021	<0.001
	26	0.009±0.010	0.019±0.012	0.001
	Overall	0.019±0.016	0.009±0.012	<0.001
D value	17	0.086±0.024	0.054±0.027	<0.001
	16	0.069±0.018	0.048±0.019	<0.001
	15	0.048±0.016	0.041±0.019	0.111
	14	0.036±0.013	0.038±0.015	0.665
	13	0.031±0.013	0.034±0.012	0.377
	12	0.015±0.011	0.021±0.008	0.017
	21	0.021±0.009	0.029±0.010	0.012
	22	0.040±0.021	0.058±0.023	0.006
	23	0.055±0.023	0.079±0.037	0.006
	24	0.064±0.018	0.102±0.050	0.001
	25	0.078±0.022	0.126±0.067	0.002
	26	0.102±0.030	0.147±0.080	0.013
	27	0.118±0.038	0.160±0.099	0.051
	Overall	0.072±0.064	0.059±0.037	0.001

Table 3. Linear mixed model analysis (㎜). Estimated mean values ± standard error (SE) between master group and test group.

	Group CI	Group IOS	*p*-value
X	0.003±0.001	0.007±0.001	0.001
Y	0.007±0.001	0.010±0.001	0.024
Z	0.003±0.001	0.008±0.001	<0.001
D	0.010±0.001	0.014±0.001	0.006

3. Precision

The precision values showed the significant difference between conventional impression method and digital impression using an intraoral scanner at every three-dimensional coordinate except X15 and Z22. The conventional impression method showed consistently lower values than digital impression using an intraoral scanner at every tooth position (p <0.05) (Table 4). Conventional impression method showed more precise than digital impression using an intraoral scanner.

Table 4. Precision values (㎜). Mean discrepancies values ± standard deviation (SD) between master group and test group.

	Position	Group CI	Group IOS	*p*-value
X	17	0.026±0.023	0.032±0.023	0.004
	16	0.018±0.018	0.026±0.019	<0.001
	15	0.017±0.014	0.019±0.014	0.15
	14	0.014±0.012	0.021±0.015	<0.001
	13	0.011±0.010	0.019±0.013	<0.001
	12	0.006±0.005	0.012±0.009	<0.001
	21	0.008±0.006	0.017±0.013	<0.001
	22	0.015±0.017	0.045±0.032	<0.001
	23	0.029±0.023	0.063±0.049	<0.001
	24	0.027±0.022	0.083±0.064	<0.001
	25	0.035±0.028	0.106±0.081	<0.001
	26	0.045±0.034	0.126±0.099	<0.001
	27	0.049±0.039	0.143±0.109	<0.001
	Overall	0.023±0.025	0.054±0.069	0.000
Y	16	0.007±0.007	0.022±0.016	<0.001
	15	0.007±0.006	0.026±0.019	<0.001
	14	0.006±0.004	0.027±0.020	<0.001
	13	0.015±0.016	0.020±0.014	<0.001
	12	0.009±0.013	0.013±0.009	<0.001
	21	0.009±0.007	0.018±0.014	<0.001
	22	0.017±0.013	0.024±0.017	<0.001
	23	0.016±0.015	0.021±0.015	<0.001
	24	0.016±0.013	0.020±0.014	0.001
	25	0.020±0.015	0.029±0.021	<0.001
	26	0.029±0.022	0.044±0.036	<0.001
	27	0.038±0.029	0.064±0.053	<0.001
	Overall	0.015±0.017	0.027±0.027	0.000

Z	16	0.007±0.006	0.015±0.010	<0.001
	15	0.011±0.010	0.022±0.015	<0.001
	14	0.014±0.014	0.022±0.015	<0.001
	13	0.015±0.016	0.020±0.014	<0.001
	12	0.009±0.013	0.013±0.009	<0.001
	21	0.012±0.013	0.014±0.010	0.003
	22	0.023±0.023	0.025±0.017	0.238
	23	0.025±0.022	0.032±0.023	<0.001
	24	0.021±0.018	0.033±0.024	<0.001
	25	0.019±0.015	0.028±0.022	<0.001
	26	0.013±0.011	0.018±0.014	<0.001
	Overall	0.015±0.016	0.022±0.018	0.000

IV. Discussion

The aim of the current study was to introduce a new method to evaluate the three-dimensional accuracy of a complete arch impression. Additional purpose was to compare the accuracy of conventional impression and intraoral digital scan using the method introduced.

Previous studies evaluated the accuracy of dental impression using various methods. For evaluation of conventional impression, visual inspection of misfit with naked eye and microscope or measuring differences of distance between reference points were performed.[28, 30, 32] Superimposition technique, measuring the accuracy by superimposing the master model and definitive casts was also used.[18, 21, 26, 33, 34] Especially, proper methods were not suggested for evaluating the accuracy of digital impression using intraoral scanner without superimposition technique. However, these methods have several limitations. Visual inspection of misfit was subject to inspectors and measuring differences of distance between reference points only consider linear distance, so vertical differences were not evaluated.[20] Former studies to evaluate the accuracy of dental impression using superimposition technique had errors during superimposition process. Sebastian et al. evaluated accuracy of intraoral scanners with “Best fit algorithm” using superimposition and most datasets showed inaccuracies in molar region and concluded that it might be due to incorrect software stitching processes and accumulated errors during data processing.[23]

In the current study, evaluating three-dimensional distortion of each tooth was possible due to evaluating movement of centroids itself and introduced a novel method for evaluating the accuracy of optical or conventional impressions. Although, some studies did not use superimposition, these studies did not evaluate complete arch or completely 14 teeth.[16, 35, 36]. In the current study, basic geometry was used using typical cylinders instead of natural tooth. Three-dimensional coordinate system was introduced to measure distortion of conventional and digital impression techniques to exclude the inherent errors while superimposing digital models to compare the amount of distortion. Moreover, this was the first study to evaluate the accuracy of complete arch impressions by using three-dimensional coordinate system. Using this method, introduced by the current study, superimposition was not needed to analyze the accuracy of intraoral scanner and the three-dimensional distortion of each tooth position could be measured. Further studies could analyze the accuracy of any intraoral scanner or conventional impression material by using this method.

Considering additional aim of the current study, conventional impression showed more accurate than digital impression using intraoral scanner with most results of two-sample t-test and linear mixed model, therefore the null hypothesis was rejected. This finding was in agreement with other studies evaluating the accuracy of complete-arch digital impression method compared with conventional impression method. Ender et al evaluated the complete arch impression accuracy of intraoral digital impression method and conventional impression method.[25] They reported that the digital impression method was less accurate and showed different pattern of deviation than conventional impression method. Kuhr et al evaluated trueness and precision of complete arch digital impression using various intraoral scanners compared with conventional impression. They reported that conventional impression method significantly more accurate than intraoral scanners.[20] Recent study also reported digital impression method using intraoral scanner was less accurate than conventional impression method on partial or full arch.[37] But another studies reported that digital impression using intraoral scanner showed comparable accuracy with conventional impression method on quadrant impression.[34] In the current study, conventional impression method showed significantly more accurate than conventional impression method. No general agreement has not yet been reached on how much accuracy is needed for the clinical procedure. Wesemann et al. concluded that full-arch scans with deviations of less than 30㎛ were classed as “excellent”, less than 140㎛ as “very good”, less than 250㎛ as “acceptable”, and above 250㎛ as “insufficient”.[38] Both precision and trueness values were less than 250㎛, so both methods were clinically considered to be used without problems.

One of the limitations of the current study was scanning in vitro procedure. Scanning in the mouth had difficulties due to saliva, blood or metallic restoration. Another limitation is the identical shape of PEEK cylinder compared with the tooth having various anatomical shape. In a pilot study, the master model without irregular patterns had problems to be scanned. It was due to identical PEEK cylinder shape. Most intraoral scanners capture many images and combine to three-dimensional data sets. However, during combination procedure, confusion is occurred due to the identical cylinder shape. Therefore, in order to scan the model, various irregular patterns were engraved at the master model for favorable scanning. Last, only one intraoral scanner was used in the current study. Intraoral scanners used in the clinical situation has various accuracies and characteristics. Therefore, further studies should verify the accuracy of other intraoral scanners using the same method.

V. Conclusion

Within the limitations of current in vitro study, following conclusions were drawn:

1. By using this new method, a three-dimensional evaluation of full-arch impression accuracy was possible.

2. Trueness, based on independent two-sample t-test, most results showed that conventional impression method was more accurate than digital impression using an intraoral scanner. Based on the linear mixed model, all results showed that conventional impression method was more accurate than digital impression using an intraoral scanner.

3. Precision, based on independent two-sample t-test, results showed that conventional impression method was more accurate than digital impression using an intraoral scanner.

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국문요약

전악 인상 모형의 3차원적 정확도 비교를 위한 새로운 접근

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서 권 수

인상 채득 시 정확도를 평가하는 몇가지 방법들이 있지만 각각의 방법들에 있어 몇가지 한계점들이 존재한다. 이번 연구의 목적은 구강 스캐너를 이용하여 채득 된 디지털인상을 포함한 서로 다른 인상 채득 기법의 3차원적인 정확도를 평가하는 새로운 방법을 제시하는 것이다. 추가적으로 이러한 방법을 이용하여 전통적인 인상채득법과 구강 스캐너를 이용한 디지털인상의 정확도를 비교해 보았다.

Polyetheretherketone재질로 제작된 직경 5mm, 길이 15mm의 맞춤형 원기둥 14개와 상악 환자 모형으로 기준 모델 제작을 제작하였다. 각각의 원기둥들은

환자 모형의 각각의 치아 위치에 위치 및 고정되었고 대응되는 치아를 원기둥이 대신하였다. 기준 모형을 전통적인 인상 채득 방법을 이용해 복제하여 25개의 석고 모형이 제작되었다. 또한, 기준 모형을 구강 스캐너를 이용하여 스캔을 시행, 25개의 디지털 모형을 제작하였다. 원기둥 장축의 중심 좌표(Centroid)를 구하기 위해 2가지 각기 다른 방법이 이용되었다. 물리적 모형이 존재하는 기준 모형과 석고 모형은 3차원 측정기 (CMM)을 이용하여 원기둥 장축의 중심 좌표를 구하였고, 가상 모형의 경우 별도의 소프트웨어 (Geomagic Control X, 3D systems, USA)를 이용하여 원기둥 장축의 중심 좌표를 구하였다. 각각의 원기둥 장축의 중심 좌표들의 변위를 구하기 위해 3차원적인 좌표계를 도입하여 설정하였다. 또한 각각의 치아 위치에서 기준 모형과의 석고 모형 및 가상 모형 원기둥 중심좌표간의 거리 값인 ΔD를 구하였다.

이를 통해 정확도(trueness, precision)를 구하고 분석하였다. Trueness값의 경우 대부분 치아 위치의 결과값에서 전통적인 인상 채득 방법이 구강스캐너를 이용한 디지털 인상 채득 방법에 비해 유의하게 더 정확한 값을 나타내었다. 선형 혼합 모델 분석에서도 각각의 좌표 및 ΔD 에서 전통적인 인상 채득 방법이 구강스캐너를 이용한 디지털 인상 채득 방법에 비해 유의하게 더 정확한 값을 나타내었다 (p <0.05). Precision의 경우도 마찬가지로 전통적인 인상 채득 방법이 구강스캐너를 이용한 디지털 인상 채득 방법에 비해 유의하게 더 정확한 값을 나타내었다.

이번 연구에서 전악 인상 채득시의 정확도를 평가할 수 있는 새로운 방법을 제시하였고 사용할 수 있었다. 이러한 방법을 이용하여 전악 인상 채득시 3차원적인 분석이 가능하였다. Trueness 및 precision 모두에서 전통적인 인상채득 방법이 구강 스캐너를 이용한 디지털 인상보다 정확함을 알 수 있었다.

핵심 단어 : 전통적 인상, 디지털 인상, 정확도, 전악