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엔도크라운 디지털 인상을 위한 구강스캐너 3종의 정확도 평가: 실험실 연구

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Evaluation of the accuracy of three different intraoral scanners for endocrown digital impression: An *in vitro* study

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Purpose: The aim of this *in vitro* study was to evaluate the accuracy of three different intraoral scanners (IOSs) on digital impressions of different types of endocrown cavity preparations. **Materials and methods:** Two human mandibular molar teeth were prepared with different endocrown abutment designs: one with a buccal wall (Class 2) and the other without a buccal wall (Class 3). Both cavity designs were scanned using a reference desktop scanner (E3) and three different intraoral scanners: Trios3 (TRI group), Cerec Omnicam (CER group), and i500 (I5 group). The obtained Standard Tessellation Language (.stl) datasets were exported to metrology software. The precision was evaluated based on deviations among repeated scan models recorded by each IOS. The trueness was evaluated based on deviations between the reference data and repeated scans. For detecting interaction, data were statistically analyzed using a univariate analysis of variance (ANOVA) and for analyzing the comparison of the test groups data were analyzed by one-way ANOVA and post-hoc Tukey test at the significance level of .05. **Results:** The deviation values for both cavity designs in the I5 group were significantly lower than those in the other IOS groups in terms of trueness. For both cavity designs, the TRI group exhibited better precision than the other IOS groups. **Conclusion:** Different technologies of IOS device's and different endocrown prepration designs affected the accuracy of the digital scans. *(J Korean Acad Prosthodont 2020;58:282-9)*

Keywords: Cavity design; Endocrown; Intraoral scanners; Precision; Trueness

Introduction

Caries, physical trauma, abrasions, and erosion can lead to severe loss of tooth structure, and the majority of these cases are treated with endodontic therapy.[1] Fractures may occur when endodontically treated teeth are subjected to intense stress under functional forces.

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Fractures are often observed in post-core restorations. Ceramic inlays and onlays and endocrown restorations are alternative treatment approaches for nonvital teeth, which exhibit substantial tissue loss.[2]

In recent years, endocrown restorations have become popular in restorative dentistry due to several advantages, such as providing adequate function and esthetics, conservative and biomechanical integrity. There are many published studies on various aspects of endocrown restorations. Among these, different crown preparation and cavity designs are a common focus, and various methodologies to fabricate endocrown restorations have been described.[3] Endocrown restorations are bonded to the intaglio surfaces of the pulp chamber and the margins of the teeth. Achieving the micromechanical retention provided by the axial surfaces of the teeth and pulp chamber and related with preparation design is a very important point on the clinical success and adhesive cementation.[3] Nevertheless, there is no standardization presented for the preparation of endocrown restorations, particularly regarding of the residual amount of tooth structure and specific tooth preparation.[2]

There are particularly two important factors for endocrown preparation, one is the internal part of pulp chamber, and the other is amount of residual tooth walls. The preparation height at the pulp chamber mainly suggested as 2 mm for endodontically treated molars.[4] However, the amount of residual tooth walls, providing ferrule effect, creation of the butt margin at the gingival level are variables which can influence the retention success of the restoration.[2] Three classification have been made in terms of residual tooth tissue amount after endocrown preparation. Class 1 describes a tooth preparation which have at least two axial walls such as buccal and lingual, Class 2 type of preparations have got at least one axial walls remaining such as buccal or lingual axial wall and finally Class 3 describes a tooth preparation which have no cuspal walls and all walls are circumferentially reduced.[2]

Nowadays, fabricating endocrown restorations using a digital workflow is very popular.[5,6] The use of digital technology is rapidly growing in all fields of dentistry, with new-generation intraoral-scanners (IOSs) appearing on the market at regular intervals. IOSs today are more accurate and easier to use than those available in the past. With developments in technology, the indications for IOSs have grown, and IOSs are now a common feature of clinical dentistry today[7] and digital impressions provided a strong alterantive to conventional impression technques.[8]

As described by ISO-5725 accuracy of a digital impression is defined by two independent factors: trueness and precision.[9] Trueness is obtained by comparing the geometries of the original model and digitized model, and precision is obtained by comparing the geometries of the digitized models recorded by the same IOS.[9]

The digital impression accuracy mostly had been evaluated on single crowns, bridges, full arch and implant supported restorations while the results were showed differences.[10-12] For full arch scanning the precision of different IOS's have been reported ranged between 30.9 - 60.1 μm and the trueness values declared 15 - 30.8 μm.[8] In a previous research it was reported the precision of single-tooth intraoral impressions were reported 13.33 μm in the anterior region and 7.0 μm for the posterior region.[13] Add to this, a previously published research on the accuracy of single-tooth digital impression was declared as trueness values between 6.9 - 27.9 μm and precision values between 4.5 - 13.3 μm.[13] However, Carbajal Meija *et al*. were found the trueness values 19.1 μm and precision values 11.9 μm.[13] Nevertheless, in a digital workflow, optimal endocrown preparation is paramount, and limited data on accuracy of impression are available in the literature.

Dental models must have high accuracy to increase the success of dental restorations.[13] Several studies have evaluated the trueness and precision values of digital impressions obtained by IOSs.[9,10,12] Recent studies that evaluated the accuracy of digital impressions emphasized the need for scientific evidence on accuracy of impressions to support the use of digital impressions.[14] The accuracy of short-scan digital impressions, such as those of a single tooth or quadrant and sextant areas, are comparable with that of conventional impressions. However, in long-span impressions, improvements are needed for the digital impressions to be comparable with conventional impressions.

The accuracy of digital impressions in single crown restorations has been well researched.[15] However, there is insufficient research on digital impressions of endocrown cavities. The aim of this *in vitro* study was to evaluate the accuracy of three IOSs in terms of digital impressions of two different endocrown cavity designs. The null hypothesis of this study was that there would be no significant difference in the accuracy of the IOS in terms of the different preparation geometries.

Materials and methods

Two human mandibular molar teeth with a pulp chamber were prepared to obtain digital impression models, and two different endocrown cavity designs Class 2 and Class 3 were created (Fig. 1). In the first tooth model, the pulp chamber (2.5 mm in depth from the cemento-enamel junction [CEJ]) was removed. The lingual, mesial, and distal coronal portions were then prepared to 1.5 mm from the CEJ, and the buccal coronal portion was prepared to 3 mm from the CEJ (Class 2). In the second tooth model, the pulp chamber (2.5 mm in depth from the CEJ) was removed, and all axial walls were prepared to 1.5 mm from the CEJ (Class 3). The preparation depth was measured using a digital caliper (Absolute Digimatic; Mitutoyo, Tokyo Japan). The path of insertion was evaluated in terms of the pres-

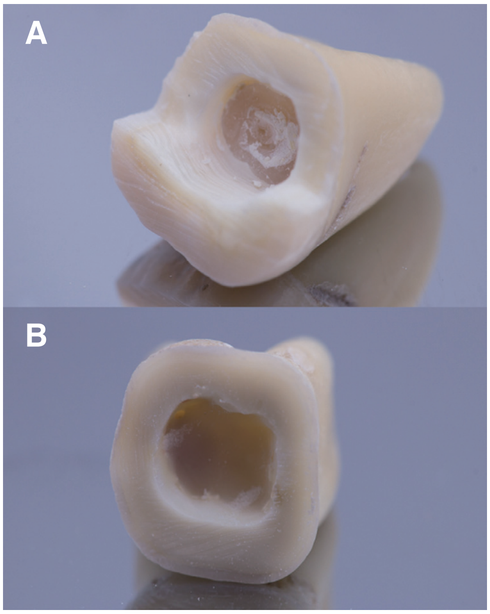

Fig. 1. Endocrown cavity preparations. (A) Preparation with a buccal wall, (B) Preparation without axial wall.

ence of undercut/interference. One trained practitioner completed all the preparation procedures. Institutional approval was obtained from the Ondokuz Mayis University Ethics Board for Non-invasive Procedures (14.09.2017-1273).

The following three IOSs test group were evaluated: TRI group; Trios3 (3shape, Copenhagen, Denmark), CER group; Cerec Omnicam (Dentsply Sirona, York, PA, USA), and I5 group; i500 (Medit Corp., Seoul, Korea). A desktop laboratory scanner (E3; 3shape, Copenhagen, Denmark), with accuracy of 7 µm according to IS012836:2015 was used as a reference scanner in the trueness evaluation with IOS test groups. Technical details on the scanners, including software versions, are presented in Table 1.

First, the reference model was scanned using the desktop scanner (n = 10). After the scanning process was completed, the obtained scan data were used to validate the data which obtained form IOS's. One dataset was randomly selected as the reference dataset (R1) for the trueness measurements of three IOS. To standardize the data file format, the datasets obtained from the different scans were converted to a Standard Tessellation Language (.stl) file format directly via the manufacturer of the system or IOS using a manufacturer-certified software. One experienced operator obtained all the scans.

Each endocrown model was scanned 10 times by each IOS. Accuracy was evaluated by calculating the trueness and precision values. Trueness was defined as the closeness between the reference data and a test object, and precision was defined as the closeness of repeated measurements of the test object (ISO 5725-1). The R1 data

Table 1. Working principle of IOS devices

IOS	Manufacturer	Technology	Software	Light source	Acquisition method
TRI	3shape	Parallel confocal	Design Studio V.19.3.1	Light	Image
CER	Dentsply Sirona	Active triangulation	Cerec V. 4.6.1	Light	Video
I5	MEDIT Corp.	Active triangulation	MeditLink V.2.1.2	Light	Video

*IOS = intra-oral scanner; I5 = i500; CER, = Cerec Omnicam; TRI = Trios3.

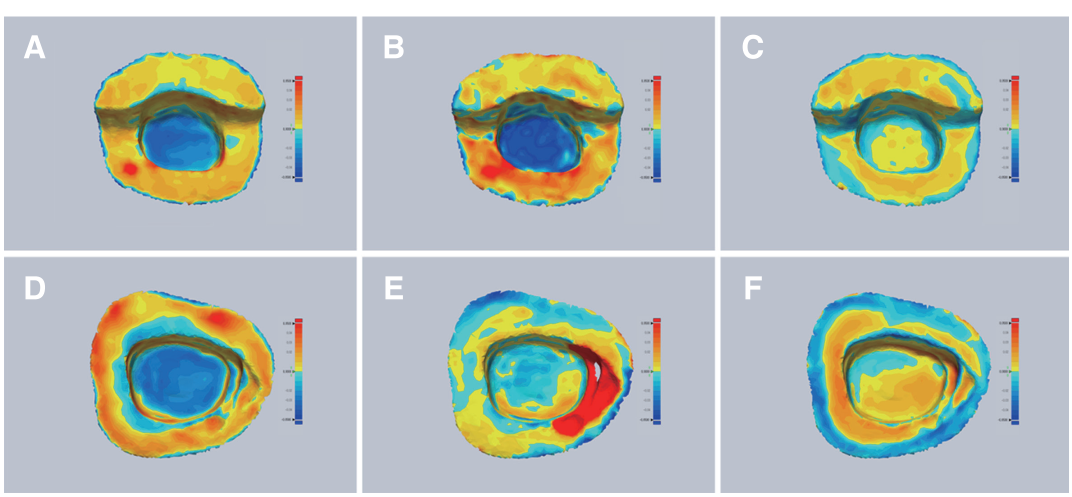

Fig. 2. Superimposition of scan data for trueness analysis. (A) Trios3 scan of the buccal wall model, (B) Omnicam scan of the buccal wall model, (C) i500 scan of the buccal wall model, (D) Trios3 scan of the model without wall, (E) Omnicam scan of the model without wall, (F) i500 scan of the model without wall.

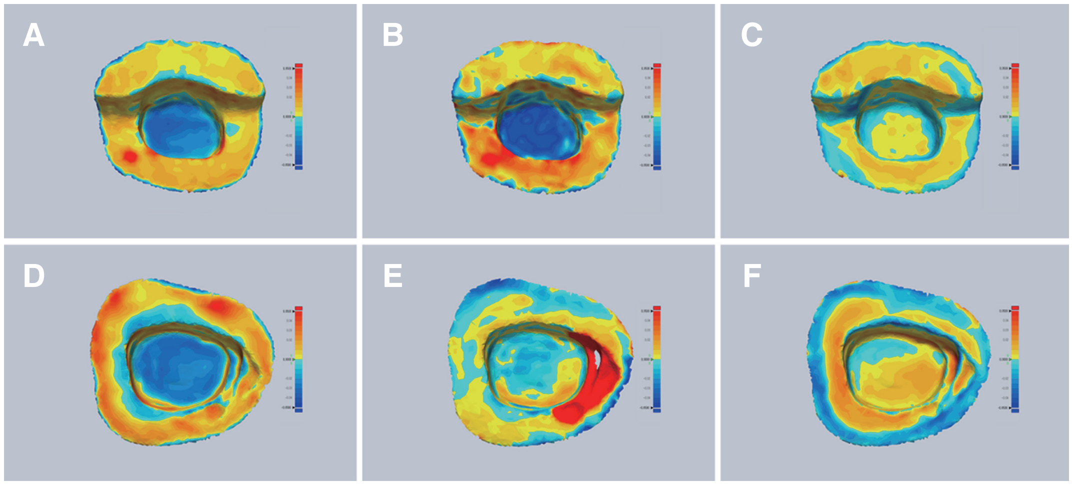

Fig. 3. Superimposition of scan data for precision analysis. (A) Trios3 scan of the buccal wall model, (B) Omnicam scan of the buccal wall model, (C) i500 scan of the buccal wall model, (D) Trios3 scan of the model without wall, (E) Omnicam scan of the model without wall, (F) i500 scan of the model without wall.

were employed as the reference data for evaluating the trueness of the data acquired by each IOS. All the datasets were then exported to a metrology software platform (Geomagic Control X, 3d Systems, Rock Hill, SC, USA), which enables superimposition of the STL files and reports average, maximum, and negative deviation values, along with standard deviations. In the trueness analysis, each scan data was superposed onto the R1 data (Fig. 2), and the average deviation between the scan data and R1 data was considered as the trueness of the scan data. In the precision analysis, 10 scan data obtained by the same IOS were superposed onto each other using metrology software platform (Fig. 3), and the average deviation between 45 pair comparisons was used to determine the precision. Both the trueness and precision analysis were evaluated after conducting the best fit alignment function that works with the iterative closest point algorithm, which provides a standard method for aligning digital 3D files. Deviations between polygons formed by the point cloud constituting the two superimposed scans were calculated, and the distance data of all the superimposed pairs were summarized.

The data were statistically analyzed using SPSS Statistics for Windows, Version 21.0 (IBM Corp., Armonk, NY, USA). The statistical differences between the groups and their interactions were evaluated using a univariate analysis of variance (ANOVA). Multiple comparisons between the IOS groups were evaluated by a one-way ANOVA, and multiple comparisons between the two endocrown cavity preparations were evaluated via independent samples T-tests. The significance level was considered .05 for all statistical tests.

Results

The univariate ANOVA test results for the trueness analysis are shown in Table 2 and those for the precision analysis are shown in Table 3. According to univariate ANOVA test results of the study, the accuracy of the digital impressions was influenced significantly form the preparation type and different IOS devices. Significant interaction was observed between different IOS device and different preparation designs. According to *in vitro* test results, the precision values among all the groups ranged from 3.6 µm ± 0.5 to 14.6 µm ± 3.1, and the trueness values ranged from 9.2 ± 1.2 µm to 44.6 ± 3.3 µm.

Table 2. Univariate ANOVA results for trueness analysis

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	8186.841[a]	5	1637.368	649.551	< .001
Intercept	22443.296	1	22443.296	8903.348	< .001
Ios	3615.976	2	1807.988	717.236	< .001
Wall	1912,752	1	1912.752	758.797	< .001
Ios * Wall	2658.113	2	1329.056	527.242	< .001
Error	136.122	54	2.521		
Total	30766.259	60			
Corrected total	8322.962	59			

*The difference is significant at $P < .05$.

Table 3. Univariate ANOVA results for precision analysis

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	3494.355[a]	5	698.871	218.086	< .001
Intercept	17721.181	1	17721.181	5529,.985	< .001
Ios	3040.832	2	1520.416	474.454	< .001
Wall	16.329	1	16.329	5.096	= .025
Ios * Wall	437.194	2	218.597	68.214	< .001
Error	846.004	264	3.205		
Total	22061.540	270			
Corrected total	4340.359	269			

*The difference is significant at $P < .05$.

Table 4. Mean trueness and precision values and standard deviations with statistical summaries

	Trueness		Precision	
	With wall	Without wall	With wall	Without wall
I5	$9.2 \pm 1.2^{a\ A}$	$12.3 \pm 0.9^{a\ B}$	$7.6 \pm 1.7^{a\ A}$	$6.9 \pm 1^{a\ B}$
CER	$14.5 \pm 1.2^{b\ A}$	$44.6 \pm 3.3^{b\ B}$	$10.6 \pm 1.5^{b\ A}$	$14.6 \pm 3.1^{b\ B}$
TRI	$17.3 \pm 0.8^{c\ A}$	$18.1 \pm 0.4^{c\ B}$	$5.4 \pm 1.7^{c\ A}$	$\pm 0.5^{c\ B}$

*IOS = intra-oral scanner; I5 = i500; CER, = Cerec Omnicam; TRI = Trios3. Lower case letters in a column show significant differences between scanners. Capital letters in a row show significant differences between wall designs. The difference is significant at $P < .05$.

The mean trueness and precision values and standard deviations are shown in Table 4.

In the trueness analysis, different results were observed in both endocrown models. In the model with a buccal wall, the I5 test group exhibited the lowest average deviation value (9.2 ± 1.2), whereas the TRI group exhibited the highest average deviation value (17.3 ± 0.8). In the model without an axial wall, the lowest average deviation value (12.3 ± 0.9) was obtained in the I5 group. However, the highest average deviation value (44.6 ± 3.3) was obtained in the CER group. In all IOS groups, there were significant differences between the endocrown preparation designs in terms of the trueness values ($P < .05$).

The results obtained in the precision analysis were similar for both endocrown models using all three IOSs. In the precision analysis, parallel results were observed in both endocrown models. The lowest average deviation values (with wall: 5.4 ± 1.7; without wall: 3.6 ± 0.5) were obtained in the TRI group, whereas the highest average deviation values (with wall: 10.6 ± 1.5; without wall: 14.6 ± 3.1) were obtained in the CER group. In all IOS groups, there were significant differences between the endocrown preparation designs in terms of the precision values ($P < .05$).

Discussion

In the present study, we compared and evaluated the effects of two endocrown cavity designs on the accuracy of digital impressions. The findings showed that the endocrown cavity preparation affected the accuracy of the IOS. Therefore, the null hypothesis was rejected.

Ongoing developments in intraoral scanning systems and digital impression technologies will see them replace the role of conventional impression systems in the near future. Digital impressions offer several advantages, such as ease of use, repeatability of impressions, direct visualization of impressions, and time efficiency.[16] Despite these advantages and continuing developments, distortion remains a problem in full arch scans.[17-19] Although distortion problems have been reduced in single crown scans and partial scans, a previous study concluded that digital impressions cannot replace conventional impressions especially in long span prosthesis.[20] In a recent study that compared the precision and trueness of conventional and digital impressions, the following results were presented: 12.5 ± 2.5 μm (precision) and 20.4 ± 2.2 μm (trueness) using the conventional approach and 32.4 ± 9.6 μm (precision) and 58.6 ± 15.8 μm (trueness) using the digital approach.[21] In the current *in vitro* study, the test results using the digital approach were similar trueness and precision test values to those obtained in the aforementioned study. The obtained test values for trueness, ranged between 9.2 ± 1.2 μm and 44.6 ± 3.3 μm and for precision ranged between 3.6 ± 0.5 μm and 14.6 ± 3.1 μm.

In the present study, the results obtained using the three IOSs differed, and all the test values were below the reported clinically acceptable limit of 50 μm.[14] These findings suggest that digital intraoral scanning of endocrown restorations is a suitable alternative to the conventional approach.

According to the results of this *in vitro* study, there were significant precision and trueness differences between the scanner systems. The best trueness results were obtained using the i500 scanner, whereas the Tiros3 scanner produced the best precision results. The differences in the accuracy of the scanners may be due to differences in the technology and working algorithms of the scanners. Both the Cerec Omnicam and i500 scanners utilize the active triangulation technique, whereas the Trios3 uses parallel confocal technology. Although both the Cerec Omnicam and i500 scanners use the same scanning technology, the accuracy of the two IOSs differed. Differences in the technologies of the scanners and variations in scanning protocols and software, influence the accuracy of different IOSs, as reported previously in the literature.[22,23]

In the present study, the type of endocrown cavity design also significantly affected the accuracy of the IOS systems (Fig. 1). The trueness evaluation showed that the average deviation increased when the cavity was prepared without an axial wall, this result may be related to the lack of reference points.[24] An important aspect of all IOSs is that the system uses the scan of the first image as reference and then stiches together scans of subsequent images based on the original reference image. An axial wall may provide more definite reference data when compared with teeth without an axial wall.

In the present study, the tested data set were obtained from .stl files. In the .stl file format, scanned surfaces are formed by triangles from a point cloud, which is created using a 3D scanner device.[25] A high-definition sensor creates more points and more triangles for surface reconstruction.[25] This results in a more detailed surface. The i500 IOS has two scanning options during the scanning procedure: one is normal, and the other one is high-definition (HD) scanning. In the present study, the test samples were scanned using the HD function. The differences in the trueness and precision values can be attributed to the type of scan (HD) performed.

Scanning light technology may be another explanation for the differences in the accuracy of the IOSs in the present study. In a previous study, Jeon *et al*.[26] stated that the nature of the light used by an IOS can affect its accuracy. In their study, blue light scanners showed better precision than white light scanners. In the present *in vitro* study, the Cerec Omnicam and Trios3 scanners used white light, whereas the i500 scanner used blue light. Although the precision of the i500 scanner was better than that of the Cerec Omnicam scanner, the precision obtained using the Trios3 scanner was similar to that achieved using the i500 system.

Previous research reported that when the tilt angle (i.e., when the angle exceeded the angle of the tooth's axial wall) of older scanners affected their accuracy.[13] However, newer technologies and software seem to have eliminated this problem. The software version used in the Cerec Omnicam scanner in the present study was relatively older than that used in the other two scanners. This may explain the differences in accuracy between the Cerec Omincam and other IOS systems.

In the present study, the type of endocrown cavity preparation influenced the accuracy of the IOSs. Previous research also reported that the accuracy of data acquired by IOSs was affected by the preparation design.[13] Mejia *et al*.[13] showed that different preparation angles affected the accuracy of IOSs, except for the Trios3 scanner. All IOSs in the market have a specific and optimized focal depth. Focal depth is important because it is the main factor responsible for the accuracy of the scanner.[16] To obtain accurate scan data, the scanner must be positioned in such a way as to ensure optimal focal depth. However, it is very difficult to position the scanner at an optimal focal depth. Therefore, differences in anatomy and endocrown cavity preparation may have affected the accuracy of the IOSs in the present study by affecting the focal depth.

According to previous research, intraoral digital scans of single teeth or quadrantal scans are highly accurate as compared with that of full mouth scans.[19] Intraoral scanning of one single tooth showed that the trueness was 27.9 μm for Cerec and 6.9 μm for Trios and that the precision was 13.3 μm for Trios and 10.8 μm for Cerec Bluecam.[13] Ender and Mehl[21] reported deviations of up to 170 μm in full mouth scans and trueness values as small as 6.9 μm for single tooth impressions. The results obtained in this *in vitro* study were similar to the findings of these previous studies. The variations in the results can be attributed to the different study designs.

This study has several limitations. First, although all efforts were made to simulate clinical conditions, the absence of sulcular fluid, blood, saliva, patient movements, and temperature-related distortions differed significantly from the clinical setting. In addition, only three IOS systems were tested, and only one axial wall model was created. Further studies are needed to evaluate the accuracy of newer IOSs with software updates.

Conclusion

Within the limitations of this *in vitro* study, the following result were obtained;

Different technologies of IOS's and different preparation designs regarding presence or absence of an axial wall of endocrowns effected the accuracy (precision and trueness values) of digital impressions and the test values of all the IOSs was below clinically accepted limits which was previously reported as 50 μm.

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엔도크라운 디지털 인상을 위한 구강스캐너 3종의 정확도 평가: 실험실 연구

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목적: 본 연구의 목표는 다른 유형의 엔도크라운(endocrown) 와동 형태를 세 가지 다른 구강스캐너로 디지털 인상을 채득하였을 때의 정확성을 평가하는 것이다.

재료 및 방법: 두 개의 인체 하악 대구치를 협측벽이 있는 것(Class 2)과 협측벽이 없는(Class 3), 두 가지 엔도크라운 지대주 디자인으로 치아형성 하였다. 와동 디자인 2종을 레퍼런스로 탁상용 스캐너(E3, 3shape)와 세 개의 다른 구강스캐너, Trios 3 (3shape, TRI group), Cerec Omnicam (Dentsply Sirona, CER group), i500 (Medit Corp., I5 group)로 스캔하였다. 표준 테셀레이션 언어(.stl) 데이터 세트를 얻어, 계측 소프트웨어에서 불러들였다. 각 구강스캐너로 획득한 반복된 스캔 데이터 사이의 편차에 기초하여 정밀도(precision)를 평가하였다. 기준 데이터와 반복하여 얻은 구강스캔 사이의 편차로서 진도(trueness)를 평가 하였다. 상호작용을 탐지하기 위해 데이터는 일변량 분산분석(ANOVA)을 사용하여 통계적으로 분석하였고, 실험군의 비교 분석을 위해 데이터는 .05의 유의 수준에서 일원 분산분석 및 사후 Tukey 테스트로 분석하였다.

결과: I5 군의 두 와동 형태에 대한 편차값은 진도의 측면에서 다른 구강스캐너 군에 비해 낮았다. 두 와동 디자인 모두에서 TRI 군은 다른 구강스캐너 군 보다 우수한 정밀도를 보였다.

결론: 구강스캐너의 다양한 기술과 다양한 엔도크라운 치아형성 디자인이 디지털 스캔의 정확도에 영향을 미쳤다. *(대한치과보철학회지 2020;58:282-9)*

주요단어: 와동 형태; 엔도크라운; 구강스캐너; 정밀도; 진도

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