Three-dimensional Accuracy of

Edentulous Jaw Scan

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Three-dimensional Accuracy of Edentulous Jaw Scan

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TABLE OF CONTENTS

LIST OF FiGURES

LIST OF TABLES

ABSTRACT

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Background: Currently, the process of manufacturing dental prosthetics, such as dentures or full-arch prostheses, for edentulous patients begins by taking a silicone mold of the patient’s mouth, which

is uncomfortable for the patient and time-consuming. Digital scanners exist, but are too difficult to use on edentulous patients. Improving the three-dimensional accuracy of edentulous jaw scans to the point that they can be used clinically would result in a more rapid prosthetic-making process that eliminates the difficult and complex conventional impression-making process. **Purpose of the study:** Many studies have measured the accuracy of full-arch tooth scans, but no research has yet been done on the accuracy of edentulous scans and their deformation characteristics. The aim of this study is to fill this knowledge gap. **Methods:** Edentulous maxillary and mandibular models with posterior, canine, center incisor and center palatal reference points were produced using a three-dimensional printer. The printed study models were scanned by a reference scanner (Ceramill Map 400; Amann Girrbach) and an intraoral scanner (Trios 3; 3Shape). The scanned three-dimensional surface files were inputted into imaging software (Geomagic control X; 3D System) and the coordinate axes were superimposed. Three-dimensional and reference point coordinate location comparison tests were conducted on the reference and intraoral scan files to determine the accuracy of edentulous jaw scans.

Additionally, a distance error measurement test was also performed to determine the deformation characteristics of edentulous jaw scans.

Results: Three-dimensional comparison test results showed that the trueness values were 84 ± 9.05 (RMS) and 350 ± 57.58 (RMS) in the maxillary and mandibular edentulous jaw scans, respectively. In the maxillary edentulous jaw scans, the trueness value for each reference point was between 24 μm and 72 μm along the x-axis, 6 μm and 129 μm along the y-axis, and 4 μm and 87 μm along the z-axis. The greatest error (192 ± 23 μm) was found between reference points P1 and P5 with a p-value less than 0.05. In the mandibular edentulous jaw scans, the trueness value for each reference marker was between 26 μm and 313 μm along the x-axis, 6 μm and 546 μm along the y-axis, 5 μm and 254 μm along the z-axis. The greatest error (558 ± 44 μm) was found between reference points P1 and P5 with a p-value less than 0.05. The precision values of the mandibular edentulous jaw scans were statistically higher than those of the maxillary edentulous jaw scans.

Conclusions: Based on the three-dimensional comparison and accuracy test results, the maxillary edentulous intraoral scanned surface images tended to be smaller than the reference surface models;

and the mandibular edentulous intraoral scanned surface images tended to be larger than the reference surface models. This study shows that the three-dimensional accuracy of maxillary edentulous jaw scans are statistically more accurate than mandibular edentulous jaw scans.

Key words: Edentulous scan, Three-dimensional accuracy, Scanning method, Intraoral scan

Three-dimensional Accuracy of

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I. INTRODUCTION

The first step in manufacturing most dental prostheses is making an analog impression of the patient’s teeth using silicone material, the accuracy of which ultimately affects the accuracy of the final prostheses. In order to make a precise analog impression, dentists must learn and deploy technical impression-making procedures; and patients must endure the inconvenience of having the impression material cure in their mouth. [1, 2] Beside being difficult and inconvenient, many of these impressions that are sent to dental laboratories have flaws, such as voids or bubbles, in critical locations. [3-5]

Digital intraoral scanners have been widely used in clinical practice to create molds of patients’ mouths because they can overcome the disadvantages of the analog impression-making process mentioned above.[6-8] These scanners allow dentists to easily acquire three-dimensional images of patients’ teeth, implant scan bodies, and soft tissues.[9] Güth et al.[10] reported that digital impressions were more accurate than traditional analog casts obtained using silicone impression materials. In a previous in vitro study conducted by this lab, intraoral scanners were found to be substantially more accurate than traditional impression-making methods for situations where teeth do not move, such as making impressions of single crown marginal fits or crown inner gaps.[11,12] When conducting three-dimensional scans of objects, the more complex the scanned object is, the more accurate the resulting scans will be, because the scanner can use various morphological characteristics as reference when stitching together separate images.[13-15] Similarly, three-dimensional scans of dentulous jaws are accurate enough to make molds from because the scanner can accurately stitch together images by using fixed objects, such as teeth.

However, in edentulous patients, only movable tissues, like the gums or tongue, are present in the mouth; so the scanner does not have fixed reference points from which to stitch together images to create a final three-dimensional model. Some studies have shown that edentulous scans of tissue that does not move much or at all, such as attached gingiva on residual ridges or palatal sides, may be accurate enough for clinical use, but the rest of the edentulous mouth is significantly larger and features more mobile tissue than these areas do.[16-21] Scan area size is important because each time images are stitched together to create the three-dimensional model, the potential for error is introduced. As a result, larger scan areas are more prone to error because they require more images to be stitched together to create the final model.[12] Thus, given the size and lack of markers from which to construct a three-dimensional model, edentulous jaw scans tend to be too error-prone for clinical use.

Improving the three-dimensional accuracy of edentulous jaw scans to the point that they can be used clinically would result in a prosthetic-making process that requires less patient time and eliminates the difficult and complex conventional impression-making process. Trueness and precision are different measures of accuracy.[24] Trueness is the difference between reference and test data. Precision is the comparison between test data. In this context, trueness measures how close to reality the scanner gets while precision measures how consistent the scanner is. So a scanner with high trueness but low precision would produce high-fidelity models, but only intermittently, while a scanner with low trueness but high precision would frequently produce low-fidelity models that consistently erred by the same amount. Many studies have measured the accuracy of full-arch tooth scans, but no research has yet been done on the accuracy of edentulous scans.

In this in vitro study, maxillary and mandibular complete edentulous jaw models with specially-designed reference points were used to evaluate the three-dimensional accuracy of edentulous jaw scans made with an intraoral scanner. The designed reference points served as artificial morphological characteristics in the place of teeth. The deformation characteristics of the scans were then described and the accuracy of the scans were calculated.

II. MATERIALS AND METHODS

1. Study models design

Completed maxillary and mandibular edentulous jaw models were scanned using an intraoral scanner (TRIOS 3; 3Shape) (Fig 1). The scanned three-dimensional surface files were converted to a stereolithography format by using surface editing and correcting software (Shape designer; 3Shape), which was then inputted into CAD software (Meshmixer; AutoDesk, Inc.) to design the reference points. The conical shape points were 3 mm-tall cones with circular tops with diameters of 1 mm (Fig 2). Reference points were set in the positions of the second molars, canines, and central incisors in the mandibular CAD models and additionally at the center of the palatal sides in the maxillary CAD models (Fig 3).

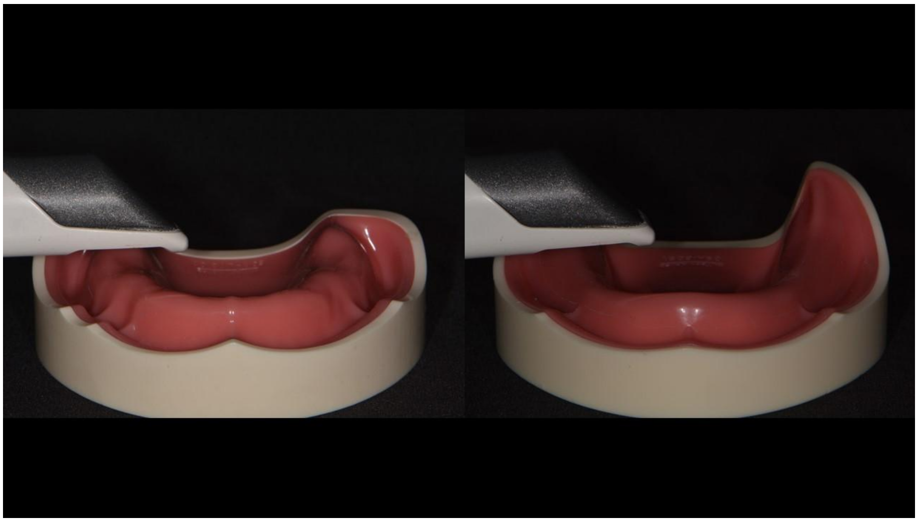


Figure 1. Completed edentulous jaw models scan

Figure 2. Reference point design

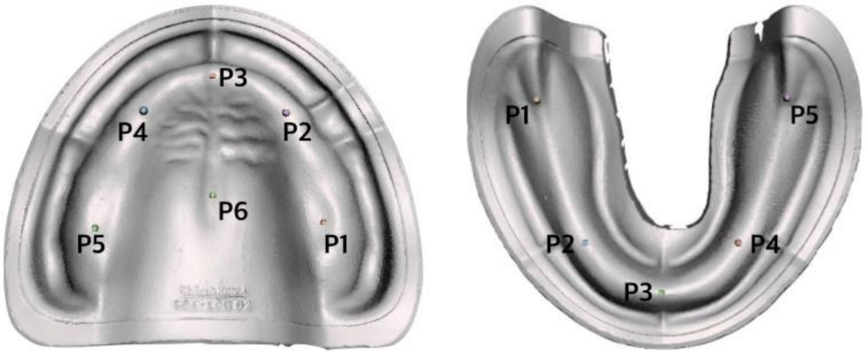


Figure 3. Designed completed edentulous jaw study models with reference points

2. Reference scan files acquisition

The models were then printed by an industrial three-dimensional printer (Projet 3510 MP; 3D Systems) and scanned by the reference scanner (Ceramill Map 400; Amann Girrbach [manufacturer's specifications: accurate to within < 20 μm]) five times per maxillary study model (RU1–RU5) and five times per mandibular model (RL1–

RL5) (Fig.4). The scanned reference scan files were imported into the imaging software (Geomagic control X; Geomagic, Inc.) to remove artifacts from visualized data sets, and the reference surface image files were trimmed to be within the boundaries of the proximal of the vestibule in every reference surface file (Fig 5).

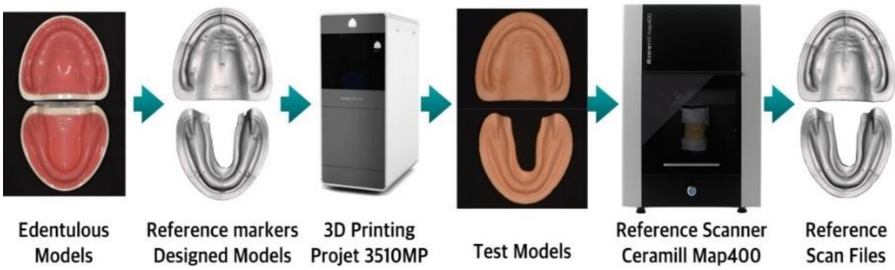


Figure 4. Reference scan files acquisition method.

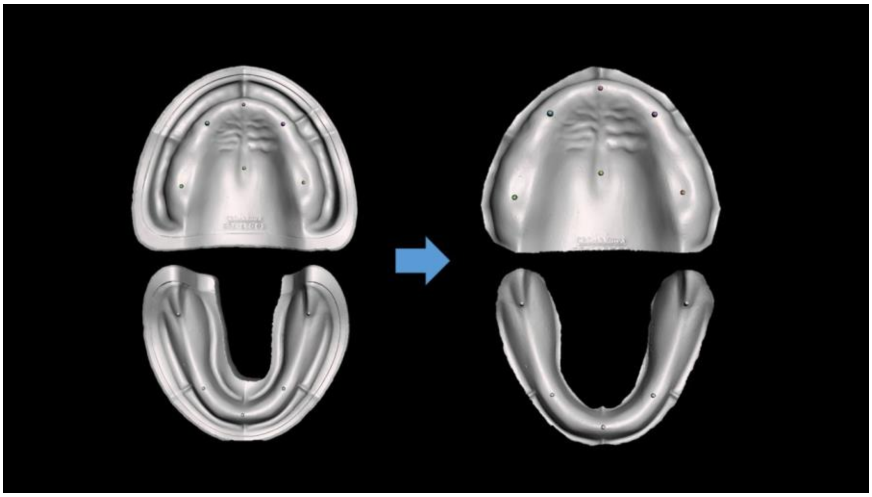


Figure 5. Reference surface files trimming.

3. Trueness measurement of reference scanner and validity test of align method

Before starting the experiment, one of the reference surface scan files was randomly selected (RU1 and RL1), and the file’s coordinate axes were set as the reference axes. The other reference files were inputted into the imaging software (Geomagic Control X; Geomagic, Inc.). The files were then aligned for best fit and compared to the selected reference scan file (RU1 and RL1) to measure the trueness of the reference scanner. The best fit alignment method performed in this study had its iterations set to 100 times. The validity of the method of the best fit alignment was tested by inputting the selected reference surface file (RU1, RL1) into the imaging software (geomagic), duplicating it, moving it to another location, and performing best fit alignment on it (Fig 6). The software then measured the difference between the reference surface files, and this procedure was repeated for both the maxillary and mandibular study models.

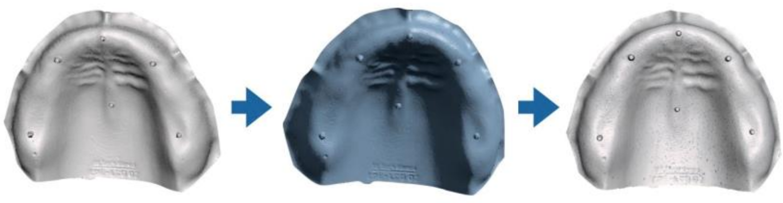


Figure 6. Best fit alignment method validate test

4. Reference values acquisition method

After performing the best fit alignment process, every reference scan file's coordinate axes were superimposed on the selected reference file. The coordinate values of the center of the tops of each reference points

(RUP1–RUP6, RLP1–RLP5) were measured five times by 3D software (Mimics 3-Matic; Matarialis) (Fig 7). Every reference points' coordinates' means and standard deviations were calculated as reference values.

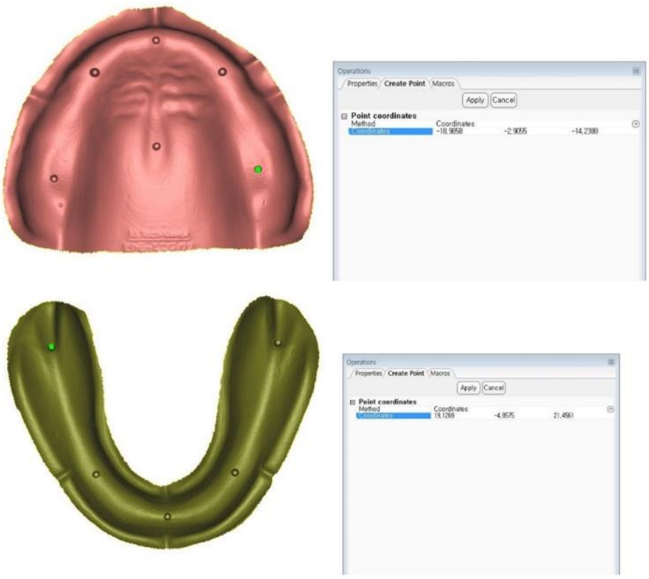


Figure 7. Three-dimensional values of the center of reference point

5. Scanning study models with intraoral scanner

To measure the trueness of the edentulous scan, the maxillary and mandibular models were scanned 10 times using an intraoral scanner (TRIOS 3; 3Shape). The scan was performed in a standard environment (mean temperature, 24℃; relative humidity, 64 percent.) An operator who had four years of intraoral scanning experience scanned the study models at 10-minute intervals (Fig 8). The maxillary edentulous study model was continuously scanned in a “W” pattern and the mandibular study model was scanned in a "zig-zag” pattern (TU1–TU10, TL1–TL10) (Fig. 9).

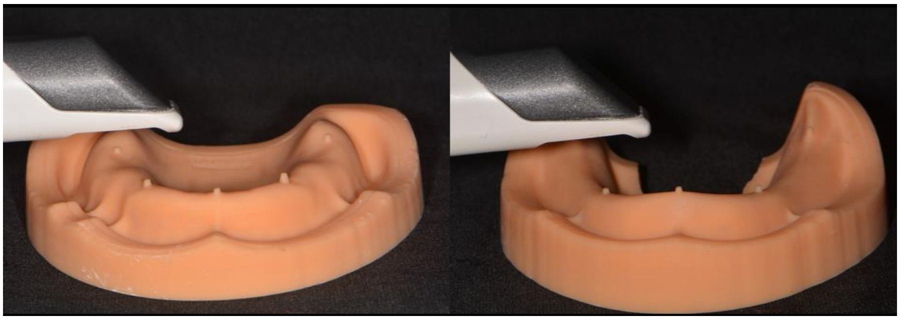


Figure 8. Study models scan.

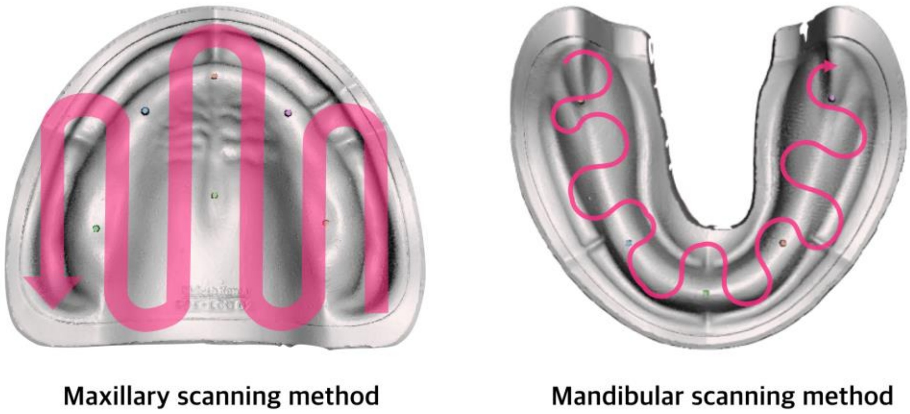


Figure 9. Edentulous study models scanning method

6. Three-dimensional trueness measurement

The intraoral scan surface files were then converted into a stereolithography file format using surface editing and correcting software (Shape Designer; 3Shape) to fit within the proximal of the vestibule in each intraoral surface file. To superimpose the coordinate axes of the intraoral scan files, the maxillary and mandibular intraoral surface files (TU1–TU10, TL1–TL10) were imported into the imaging software (Geomagic Control X; Geomagic, Inc.) to perform best fit alignment with the selected reference surface image (RU1 and RL1). The coordinate values of the center of the top of each reference points (TUP1–TUP6, TLP1–TLP5) were measured and compared with the reference values to measure the deviation of intraoral scans (Fig 10), and 3D comparison tests were also performed with the selected reference files (RU1 and RL1) to measure the intraoral scanner trueness(Fig 11). The spectrum was set for 20 colors segments, and the maximum and minimum nominal and critical values were set to ±100 μm and ±500 μm, respectively. The standard deviations and root mean square (RMS) values were then calculated.

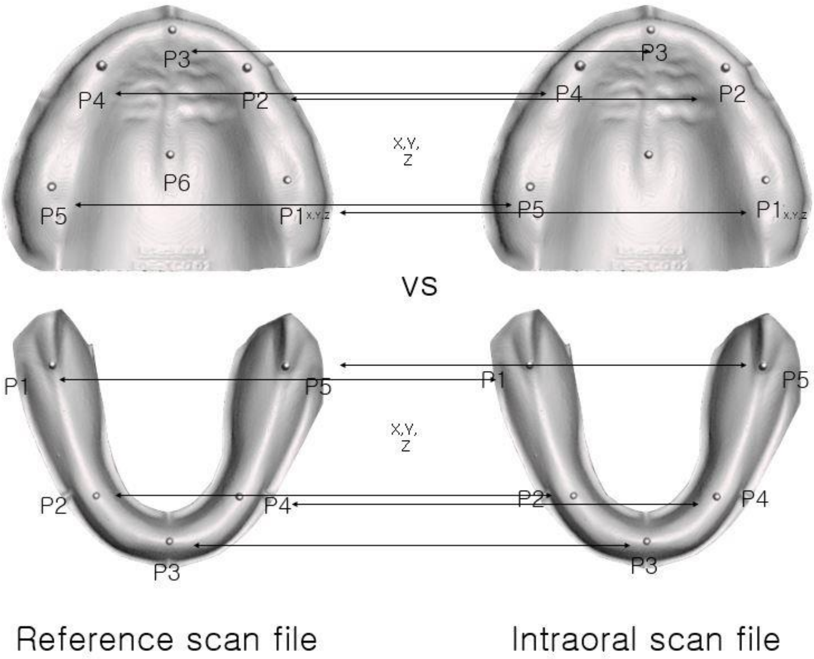


Figure 10. Three-dimensional trueness measurement

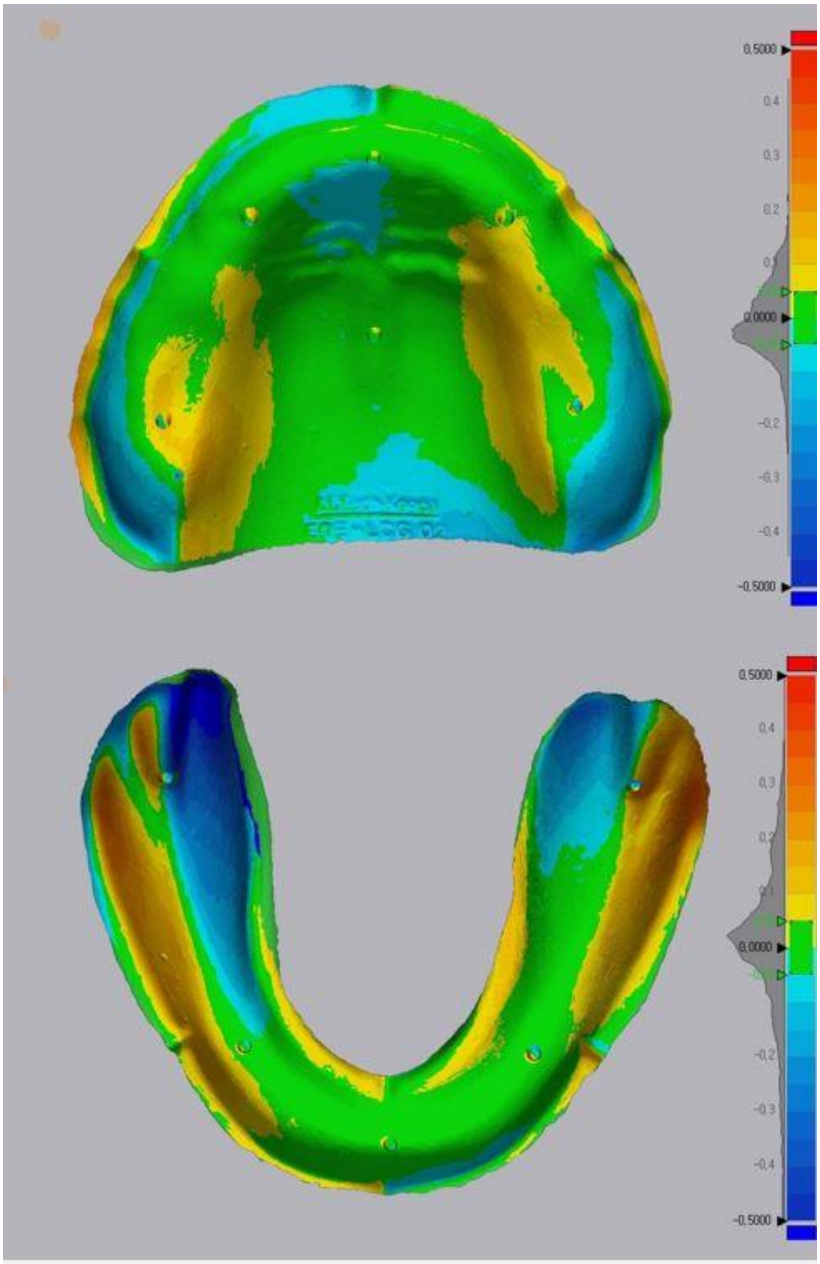


Figure 11. 3D comparison test.

7. Three-dimensional precision measurement

The intraoral surface files were all along the same coordinate axes because they were superimposed on selected reference scan files (RU1 and RL1). In this in vitro study, the reference point coordinate values for each intraoral scan file were compared to the values of the points in the same position from each other file in every axes, e.g., TPU1x_1 was compared with TPU2x_1. (Fig 12)The mean and standard deviation for each point were measured to investigate the scanner's *x*-, *y*-, and *z*-axis precision values.

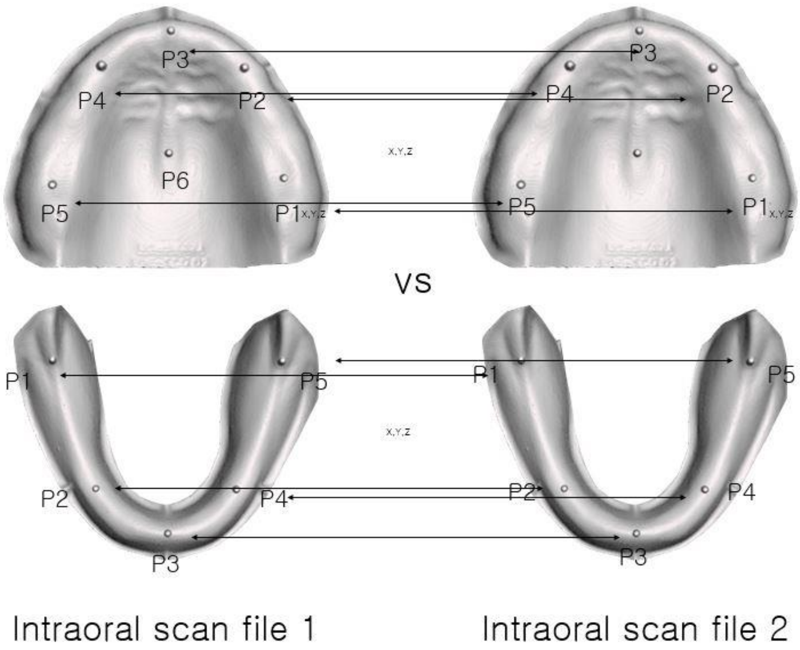


Figure 12. Three-dimensional precision measurement.

8. Distance error measurement

To further verify the experimental results of the edentulous jaw scans, the distances between reference points were tested. Using the five reference files, the mean and standard deviation for the distance between each point were set as reference data then compared against those distances in the intraoral surface images. (Fig 13)

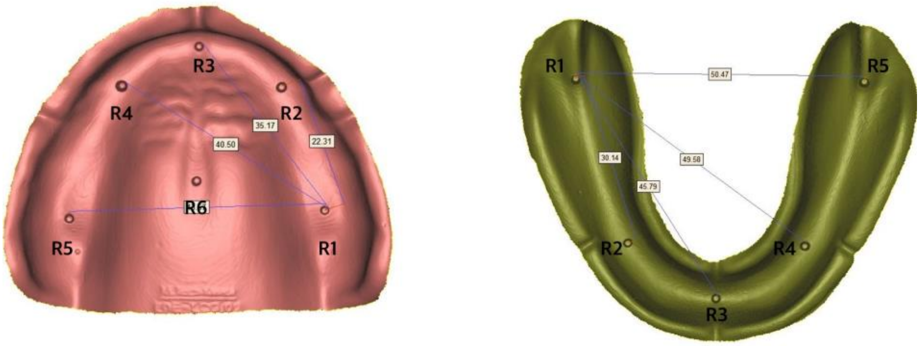
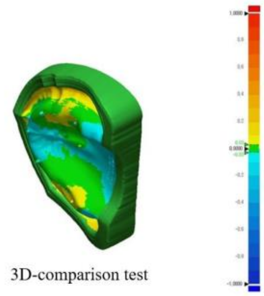


Figure 13. Distance error measurement

III. RESULTS

1. Three-dimensional accuracy of reference scanner

The manufacturer's reported tolerances for the reference scanner were basically validated. The trueness of the reference scanner was 6.3 ± 6.6 μm and 5.7 ± 7.1 μm for the maxillary and mandibular edentulous jaw scans, respectively (Fig 14). The best fit alignment method used in this study was reliable as shown by the validation tests yielding negligible registration errors of 0.001 ± 0.001 μm and 0.002 ± 0.001 μm for the maxillary and mandibular reference surface files, respectively.[25, 26]



	Maxilla (mean±SD)	Mandibular (mean±SD)	Best fit alignment (mean±SD)
RMS	6.3±6.6	5.7±7.1	0.001±0.001
SD	6.3±6.3	5.7±6.7	0.001±0.001

Figure 14. Three-dimensional accuracy of reference scanner and accuracy of align method.

2. 3D comparison test results

The comparison test results are shown in Table 1 and summarized in Fig 15. The root mean squared values for the maxillary edentulous scans were significantly lower than the mandibular edentulous jaw scans with a p-value < 0.05. For the maxillary edentulous jaw scans, as shown in Fig 15, the intraoral scanner deviated at the posterior residual ridge and the palatal side of the posterior ridge. In the mandibular edentulous jaw scans, the intraoral scanner deviated at the buccal side of the posterior residual ridge and the label side of the anterior ridge. It should be noted that, at the label side of anterior ridge, the positive and negative deviations were exchanged in the mandibular edentulous jaw scans.

	Maxillar (mean±SD)	Mandibular (mean±SD)
RMS	84±9.05	350.9±57.58
SD	83±9.1	348.7±57.41

Table 1. 3D comparison test result of edentulous jaw scan

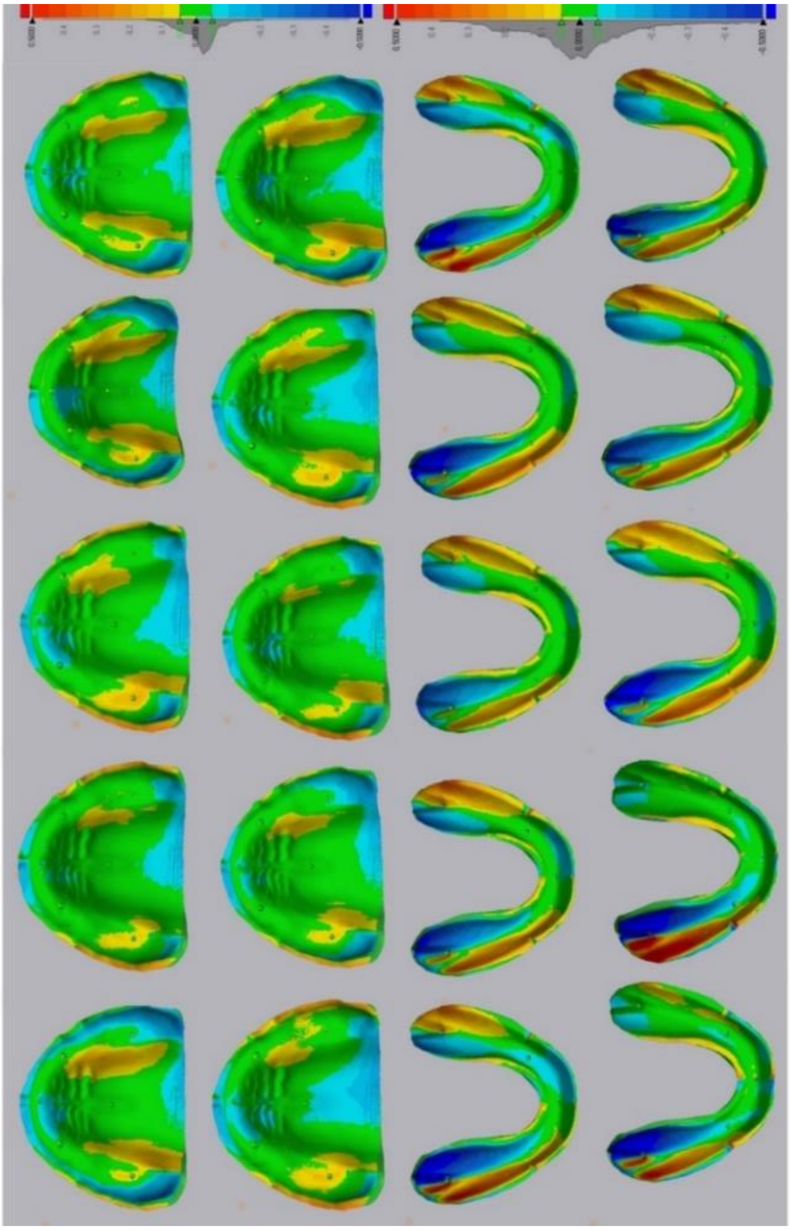
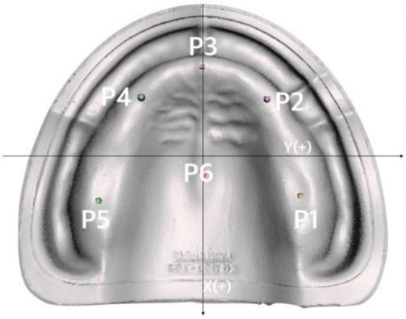


Figure 15. 3D comparison test result-color map

3. Three-dimensional trueness of maxillary edentulous jaw scanning

Fig 16A and 16B show the trueness of the reference points positions in the maxillary edentulous jaw scans. The trueness values were between 24μm and 72μm along the x-axis, 6μm and 129μm along the y-axis, and 4μm and 87μm along the z-axis. Data analysis showed statistically significant differences with a p-value less than 0.05 between the reference data and intraoral scan data, except for UP4y, UP6y, and UP6z.



	x(mean±SD)	*y(mean±SD)*	*z(mean±SD)*
P1	24±14.6	93±10.6	25±5.2
P2	65±8.7	96±8.5	14±5.2
P3	63±8.1	63±7.3	87±3
P4	72±12.1	21±8.6	28±18
P5	41±19.9	129±9.2	71±7.1
P6	30±7.9	6±17.8	4±15.7

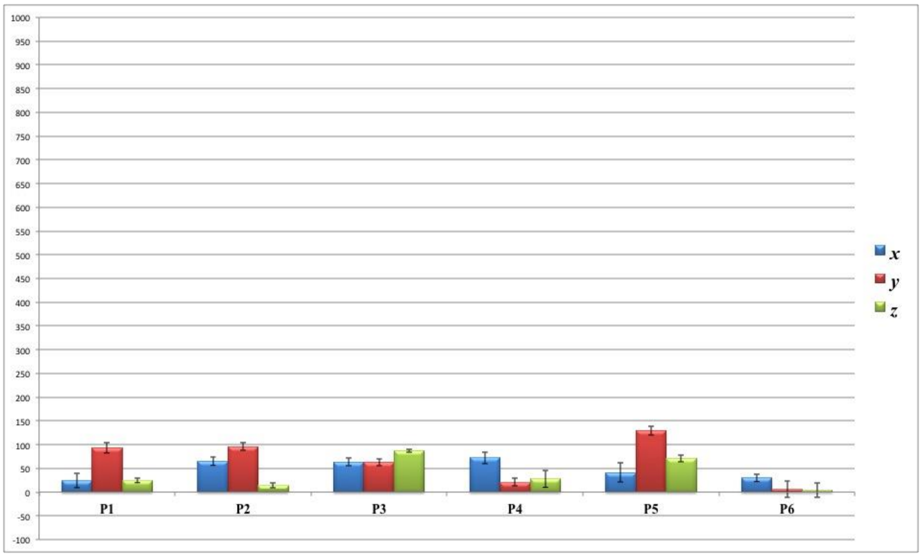


Figure 16A, B. Three-dimensional trueness in position of reference points in maxillary edentulous jaw scan.

4. Distance error measurement result in maxillary edentulous jaw scanning

The deviations in the distances between points in the maxillary edentulous jaw scans are shown in Fig 17. The greatest error (192 ± 23 μm) was found between reference points 1 and 5 with a p-value < 0.05. Based on the accuracy measurements and maxillary edentulous jaw scan comparison results, the intraoral scanned surface images tended to be smaller than the reference surface models.

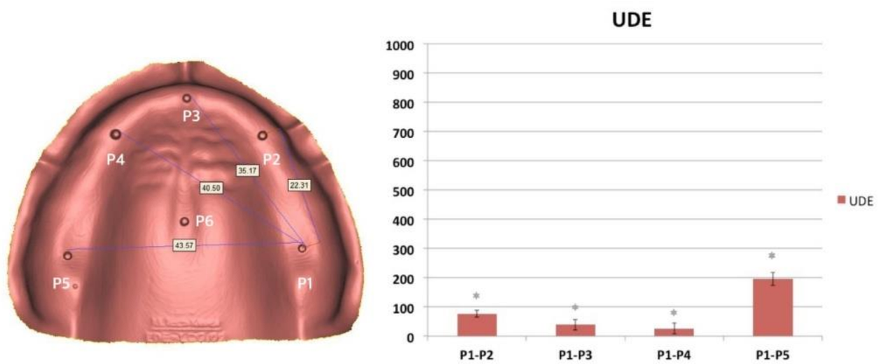
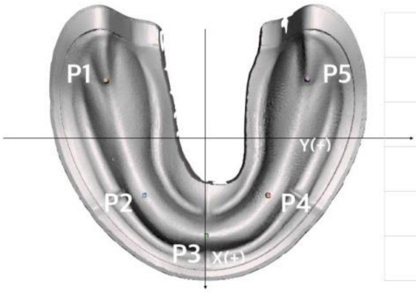


Figure 17. Distance error measurement result of maxillary edentulous jaw scan. UDE- upper jaw distance error

5. Three-dimensional trueness of mandibular edentulous jaw scanning

In the mandibular edentulous jaw scans, the trueness measurement results are shown in Fig. 18A and 18B. The trueness values were between 26µm and 313µm along the x-axis, 6µm and 546µm along the y-axis, 5µm and 254µm along the z-axis. Data analysis showed statistically significant differences with a p-value < 0.05 between the reference and intraoral scan data, except for LP2z and LP5y.



	x(mean±SD)	*y(mean±SD)*	*z(mean±SD)*
P1	313±33.8	546±39.1	254±34.8
P2	210±38.3	68±16.3	5±9.8
P3	26±12.4	227±19.6	57±8.1
P4	43±13.6	95±9.3	35±6.2
P5	59±24.8	6±10.9	126±10.7

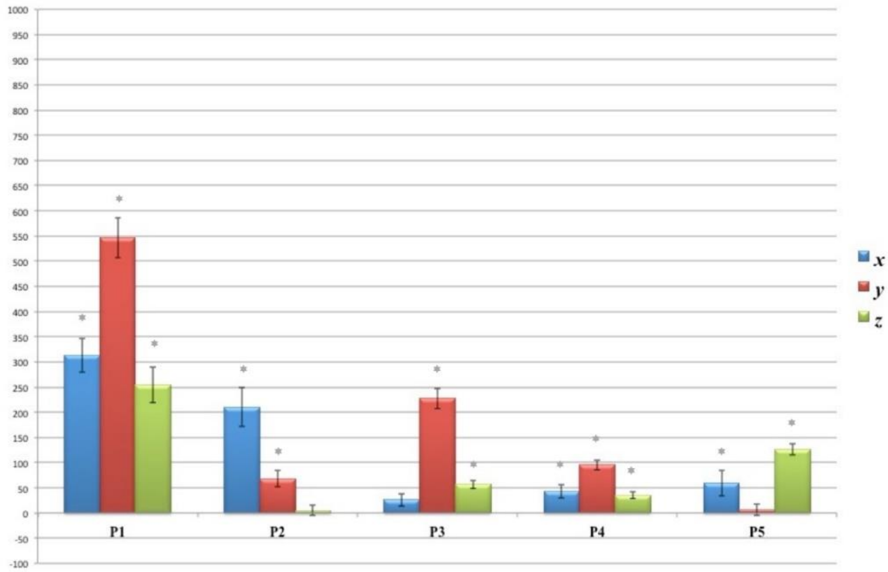


Figure 18 A, B. Three-dimensional trueness in position of reference points in mandibular edentulous jaw scan.

6. Distance error measurement result in mandibular edentulous jaw scanning

The distance error measurement results are shown in Fig 19. Starting from P1, the errors in the distances between reference markers gradually increased. The error between P1 and P5 was 558 ± 44μm, which represents a rather significant error. These results show that, during the mandibular edentulous scans, the scan image appeared to be expanding. Based on the study of the deformation characteristics of the scanned images, the scanned image expanded on the posterior side differing from that of the maxillary complete edentulous deformation.

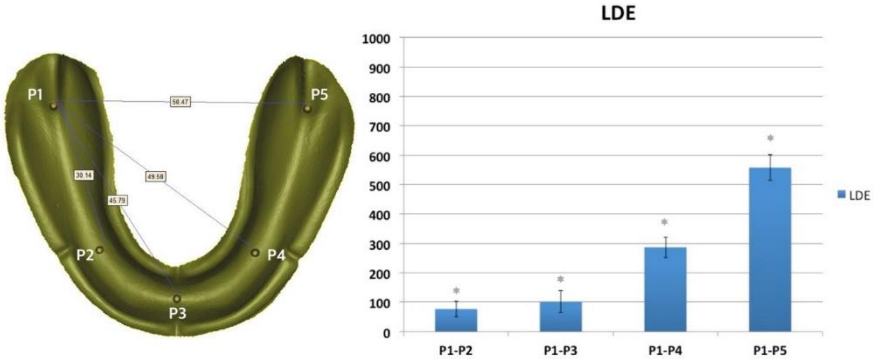


Figure 19. Distance error measurement result in mandibular edentulous jaw scan. LDE- lower jaw distance error

7. Three-dimensional precision measurement result

The precision of the edentulous jaw scans is shown in Fig 20 and Table 2. The precision values from the mandibular edentulous jaw scans were statistically higher than those from the maxillary edentulous jaw scans.

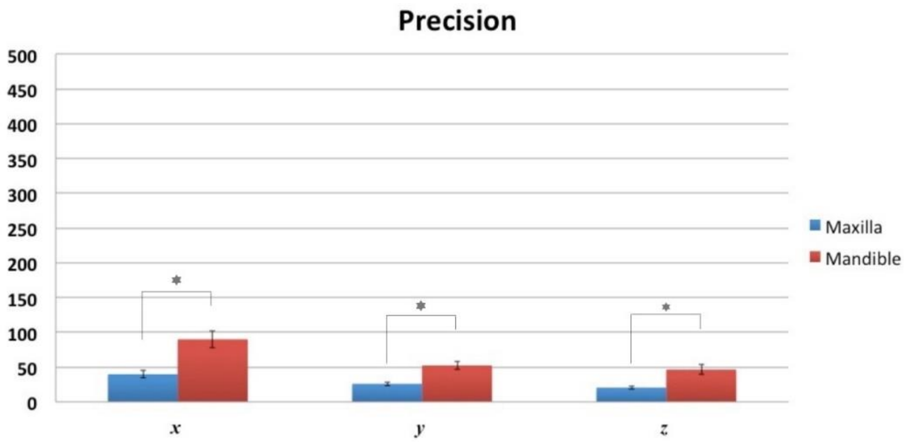


Figure 20. Three-dimensional precision values in edentulous jaw scan.

Precision	*x(mean±SD)*	***y(mean±SD)***	***z(mean±SD)***
Maxillar	39.83±5.28	26±2.72	20.5±2.22
Mandibular	90±12.35	52±5.85	46±7.01

Table 2. Three-dimensional precision values of edentulous jaw scan.

IV. DISCUSSION

Patzelt et al.[24] reported that the average trueness values based on comparison tests of edentulous scans were between 44.1 and 598.1 μm depending on the type of intraoral scanner used. However, it is difficult to confirm the deformation characteristics of surface images when edentulous scan accuracy is only measured using the comparison test method.[24, 25] This study was believed to be the first to assess the three-dimensional accuracy and deformation characteristics of edentulous jaw scans using added designed reference points. The reference points were designed to be as small as possible to maintain edentulous jaw structure characteristics. Attaching these reference markers allowed for easy and accurate measurement of the three-dimensional deviation values and the distance error between reference markers in edentulous jaw surface scans.

The distance between reference points P1 and P5 in the edentulous scans statistically significantly deviated by 196 ± 23 μm from the same distance in the reference scans. A similar scale of departure was obtained with the trueness measurements and comparison tests. According to the 3D comparison test results, the color-coded deviation map showed positive deviations at the palatal side of the posterior ridge and negative deviations at the buccal side of the posterior ridge. This finding can be explained by the fact that, when scanning a maxillary edentulous jaw, the scanned image shrinks relative to the actual object. However, Patzel (2014) found that scans of surfaces tended to be larger than their reference scan surfaces when scanning full-arch tooth models.[26] Edentulous scans must scan a wider area than dentulous scans and so must be able to precisely scan the palatal side and the residual ridge. Although no information was available in the published literature about this phenomenon, it is likely that scanning the palatal side caused the edentulous scan to be smaller than its reference scans. In edentulous patients, there is almost no morphological difference in the residual ridge and the palatal side, especially when the patient has been edentulous for a long time and has long history of denture use. When the scanned object's morphological characteristics are not clearly differentiated, errors appear during the image stitching process. Based on this tendency, it is likely that the stitching program improperly stitched the scanned edentulous residual ridge and smooth surface palatal side together, causing the edentulous scan to become smaller than its reference scan.

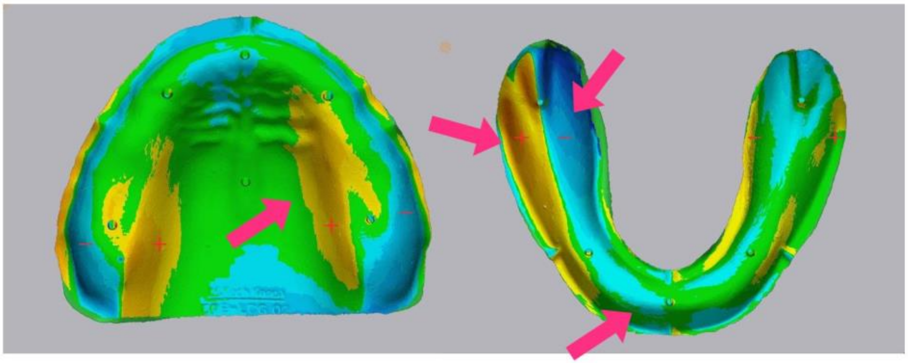


Figure 21.Deformation characteristics of edentulous jaw scanning

Unlike maxillary surface images, which tend to shrink relative to their reference scans, mandibular surface images grew relative to their reference scans. This finding was similar to the what Patzel (2014) found in their full-arch teeth scanning study.[26] The study models used in this in vitro study, although the residual ridge morphological characteristics in the mandibular edentulous jaw models was as unclear as in the maxillary jaw models, the greatest differences between the models were that the mandibular edentulous models' right and left residual ridge were not horizontally connected like in the maxillary edentulous jaw models and the anterior ridge of the mandibular jaw model area was smaller than in the maxillary jaw models. According to our data, the scanning errors mostly correlated with the morphological scanned object characteristics, and only using the narrow and poorly differentiated structure of the anterior ridge, without the connecting part of the right and left residual ridge as in the maxillary jaw, it was difficult to maintain the original shape of scanned objects. As a result, mandibular jaw scans are more fragmented and have less information about how the individual scan images fit together, resulting in the final scan being larger than the reference scan.

The precision of intraoral scans is important because the scanning process must be able to be reliably repeated. Imburgia et al.[27] reported that the precision of the TRIOS 3 scanner (3Shape), the scanner used in this study, was 67 µm when scanning a maxillary edentulous model. This study found that the same scanner achieved maximum precision values for maxillary edentulous scans of approximately 50 µm along all three axes. However, the precision values mandibular edentulous scans were as high as 100 μm. This difference was likely due to the different morphological characteristics of the jaw models, the chosen scanning patterns used to scan each model, and the direction in which the scan was performed.

CONCLUSION

This in vitro study is the first to measure the three-dimensional accuracy of edentulous scans and to analyze the characteristics of edentulous scan image deformation. We conclude that final full arch prosthetic and denture fabrication using edentulous intraoral scan data will be inaccurate due to the deformation of the scanned image and enhancements are needed before we can recommend the use of intraoral scanners for the digitization of edentulous jaws. Our study had some limitations in that the intraoral scan data in actual oral cavities is likely to differ due to the presence of blood, saliva, soft tissue, and tongue movement that may interfere with the scanning process.Further studies are required to evaluate the three-dimensional accuracy of edentulous scans using data recorded in actual oral cavities, scanning accuracy in edentulous jaw with different types of intraoral scanner, and the correlation between scanning accuracy and scanning method.

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국문초록

디지털 구강스캐너를 이용한 무치악 스캔 3 차원 정밀도 측정

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연구 배경 : 인상채득은 모든 보철물 제작 과정에서의 첫번째 가장 중요한 단계이다. 채득한 인상체의 정밀도는 최종적으로 제작된 보철물의 정밀도에 영향을 준다. 기존의 아날로그 방법으로 인상채득을 진행하는 과정에서 환자는 인상재가

구내에서 경화되는 과정 동안 불편함을 견뎌야 하고 임상가는 정밀한 인상채득을 위하여 많은 노력과 임상경험이 필요하다. 디지털 구강 스캐너의 임상적 적용은 기존의 아날로그 방식으로 인상채득을 진행하는 과정을 대체하여 빠르고 쉽게 정밀한 인상채득을 진행하는 것이 가능하게 하였다. 기존의 논문 보도에 의하면 디지털 구강 스캐너는 고정성 보철물 제작에는 충분한 정밀도를 제공하지만 전악 치아 스캔, Free-end 케이스 등 무치악 부위에 대하여서는 디지털 인상채득이 어렵고 디지털 인상 정밀도가 떨어진다고 보도하였다. 무치악 부위에 대한 디지털 인상채득 시도도 진행되고 있지만 구강 스캐너의 특성상 움직이는 연조직에 대하여서는 디지털 인상채득이 어렵고 스캔 대상체의 형태적 특성이 균일할수록 스캔과정에서 스테칭 에러 (stiching error)가 많이 발생하게

된다. **연구 목적:** 구외에서 무치악 스캔 시 구강 스캐너의 정밀도 측정에 대한 연구보도는 많이 진행 되였다. 하지만 기존의 연구 보도는 구강 스캐너로 스캔 한 인상데이터와 레퍼런스 스캐너로 채득된 레퍼런스 인상데이터를 중첩시켜 전반적인 3 차원 스캔 정밀도를 측정 하였지만 이러한 연구 결과는 무치악 스캔 시 스캔 이미지의 변형특성에 대하여서는 보도하지 않았다. 본 연구에서는 특수 제작된 상, 하악 무치악 실험모델을 제작하여 구강 스캐너 (3 Shape TRIOS 3; 3SHAPE)를 이용하여 스캔 시 스캔 이미지의 변형 특성과 무치악 스캔 3 차원 정밀도를 측정하고자 한다. **실험 방법:** 상, 하악 완전 무치악 실험모델을 구강 스캐너로 스캔하고 CAD 프로그램을 이용하여 상, 하악 무치악 스캔 이미지에서 레퍼런스 포인트를 디자인 하였다. 레퍼런스 포인트 높이는

3mm, 상단부 직경은 1mm 인 원추형으로 디자인 하였고 디자인 위치는 좌우 제 2 대구치, 좌우 견치, 중절치 중심, 상악에는 구개측 중심 등 5 곳을 지정하였다. 디자인 된 무치악 실험모델은 공업용 3D 프린터(Projet 3510mp; 3D system)를 사용하여 프린팅 하고 study model 로 사용하였다. 프린팅 된 study model 은 레퍼런스 스캐너로 5 번 스캔하여 레퍼런스 스캔파일을 제작 하였다. 5 개의 레퍼런스 스캔 파일을 사용하여 레퍼런스 스캐너의 정밀도를 측정하였고 본 실험에서 사용되는 중첩 방법 (Best fit alignment) 방법의 정밀도를 측정하였으며 매개 스캔 파일 중 레퍼런스 포인트의 중심점 3 차원 좌표값 (*x*-,*y*-,*z*-)을 측정하고 레퍼런스 데이터로 설정하였다. 레퍼런스 데이터 채득이후 study model 은 구강 스캐너로 10 번 스캔하여 구강 스캔 파일을 제작 하였다. 제작

된 구강 스캔 파일은 레퍼런스 스캔 파일과 중첩시켜 좌표축을 모두 동일화 하였고 매개 구강 스캔 파일중 레퍼런스 포인트의 중심점 좌표를 각각 측정하여 레퍼런스 데이터와 비교하여 무치악 스캔 3 차원 정밀도를 측정하였고 추가적으로 3D comparison test, 레퍼런스 포인트 사이 거리측정 결과 등을 기준으로 무치악 스캔 시 스캔 이미지의 변형특성에 대하여 연구하였다. **실험결과:** 레퍼런스 스캔 파일과 구강 스캔 파일을 3D comparison test 시행 한 결과 스캔 오차값은 상악에서 84 ± 9.05 (RMS) 하악에서 350 ± 57.58 (RMS) 측정 되였고 상악과 하악 무치악 스캔 시 하악에서 오차가 더 많이 발생하는것으로 나타났으며 이는 통계학적으로 유의성이 있는것으로 나타났다. 상악 무치악 스캔 시 3 차원 정밀도 측정 결과 특정된 레퍼런스 포인트

위치에서 *x* 축에서는 24 µm ~ 72 µm *y* 축에서는 6 µm ~ 129 µm *z* 축에서는 4 µm ~ 87 µm 오차가 발생하는 것으로 나타났고 레퍼런스 포인트 P1 과 P5 사이 거리는 192 ± 23 µm 줄어 들었고 이는 레퍼런스 데이터와 비교 시 통계학적으로 유의성이 있는것으로 나타났다. 하악 무치악 스캔 시 3 차원 정밀도는 *x* 축에서 26 µm ~ 313 µm *y* 축에서 6 µm ~ 546 µm *z* 축에서 5 µm ~ 254 µm 오차가 발생하였고 레퍼런스 포인트 P1 과 P5 사이 거리는 558 ± 44 µm 확장 되였는데 이는 레퍼런스 데이터와 비교 시 통계학적으로 유의성이 있는것으로 나타났다. **결론:** 3D comparison test 와 특정된 포인트에서 3 차원 정밀도 측정, 특정된 포인트 사이 거리측정 비교를 통하여 무치악 스캔 시 상악 스캔 이미는 수축되는 경향이 발생하였고 하악 무치악 스캔 이미지는 확장되는 경향이 발생하는 것을 확인 하였다. 또한

상악과 하악 무치악 스캔 데이터의 정밀도 비교 결과 상악 무치악 스캔은 스캔 범위가 넓고 소요되는 시간이 더 많지만 스캔 정밀도는 하악 무치악 스캔 정밀도보다 높은것으로 나타났다.

핵심 단어: 무치악 스캔, 3 차원 정밀도 측정, 스캔방법, 구강 스캐너

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