Scanning Accuracy of Bracket Features and Slot Base Angle in Different Bracket Materials by Four Intraoral Scanners

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Scanning Accuracy of Bracket Features and Slot Base Angle in Different Bracket Materials by Four Intraoral Scanners

(Directed by Professor Chung-Ju Hwang,

D.D.S., M.S., Ph.D.)

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감사의 글

논문이 완성되기까지 따뜻한 격려와 아낌없는 지도로 이끌어 주신 존경하는 황충주 교수님께 진심으로 감사드립니다. 바쁘신 와중에도 귀중한 시간을 내어 논문을 꼼꼼하게 살펴 주시고 세심하게 조언해주신 유형석 교수님, 차정렬 교수님, 박지만 교수님, 권재성 교수님께 깊은 감사의 말씀을 전합니다. 전자현미경 사진 촬영에 도움을 주신 이채은 선생님, 통계 분석에 많은 조언과 도움을 주신 김기열 교수님께도 감사드립니다.

또한, 연세대학교 교정과 대학원에서 공부할 기회를 주신 김경호 교수님, 유형석 교수님, 이기준 교수님, 정주령 교수님, 최윤정 교수님, 황순신 교수님, 최성환 교수님께도 감사드립니다. 대학원 과정을 지지해주시고 조언해주시고 시간을 배려해주신 샘모아치과 정종철 원장님, 유필식 원장님, 직원들에게 고마운 마음을 전합니다.

마지막으로 부족한 저를 늘 사랑으로 감싸주시고 응원해주시는 친정부모님, 시부모님과 무엇보다 이 논문이 나오기까지 항상 저를 믿고 지지하고 지원해 준 존경하고 사랑하는 남편 정윤과 소중한 내 보물 가윤이에게 진심으로 고맙다는 말을 전하고 싶습니다.

2021 년 8 월 저자 씀

This certifies that the Doctoral Dissertation
of Seon-Hee Shin is approved.

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ABSTRACT

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Through the dental model acquired at the time of re-diagnosis of patients undergoing orthodontic treatment, not only the relationship between the entire dentition and the arch, but also the position of the bracket is reevaluated. To evaluate whether the bracket prescription is accurately expressed by checking the height, position, and angle of the bracket slot can help to produce a good treatment result. Orthodontic tooth movement can also be easily evaluated using IOS. The purpose of this study was to evaluate the accuracy of digital scan images of brackets produced by 4 IOSs when scanning the surface of dental model attached with different bracket materials (metal, ceramic, resin, resin bracket with metal slot).

The images scanned with a laboratory scanner and images taken with a scanning electron

microscope were used as references. Each bracket axis was set in the reference image, and the axis was set identically by superimposing with the IOS image, and then only the brackets were divided to perform quantitative and qualitative analysis. By quantitative analysis, precision and trueness were analyzed as RMS values and calculated maximum discrepancy. By qualitative analysis, the bracket wing was divided into 4 parts; upper-mesial, upper-distal, lower-mesial, and lower-distal to confirm the frequency of error more than 20 ㎛. For the bracket slot, the slot base angle and the parallelism of the slot wall were measured. The results of this study are as follows.

1. There were significant differences in the scanning accuracy of the bracket according to the type of scanner. In quantitative analysis, precision RMS was the smallest in Trios 3, followed by Primescan, CS3600, and i500 (P <0.001). Trueness RMS was smallest in Trios 3, followed by Primescan, i500, and CS3600 (P <0.001). The maximum discrepancy was the smallest in Trios 3, followed by Primescan, CS3600, and i500 (P <0.001).

2. There were significant differences in the scanning accuracy of the bracket according to the type of brackets. In the qualitative analysis, the scan accuracy of the bracket wing was the smallest in Trios 3, followed by Primescan, CS3600, and i500 (P <0.001). The parallelism measured by the difference between the upper and lower angles of the slot wall was 0.48 in SEM, 7.00 in Primescan, 5.52 in Trios 3, 6.34 in CS3600, and 23.74 in i500 (P <0.001). The difference between the manufacturer's torque and the bracket slot base angle was 0.39 in SEM, 1.96 in Primescan, 2.04 in Trios, and 5.21 in CS3600 (P <0.001).

3. The maximum discrepancy according to the bracket materials was the lowest in ceramic, followed by metal, resin and resin bracket with metal slot (P <0.05). In the qualitative analysis, the scan accuracy of the bracket wing was lower in resin and resin metal brackets than in ceramic and

metal (P <0.05). Brackets that are more translucent and transmit light, such as resin or resin brackets with metal slots, tended to show greater errors than metal or polycrystalline ceramic brackets.

This study evaluated the accuracy of the bracket only. According to the results of this study, it was possible to confirm the bracket slot base angle, which is difficult to obtain by the conventional impression method according to the scanner type. However, it must be admitted that there is some error in recognizing slots through scanning in general. Considering only the scan of the bracket in this study, Primescan and Trios 3 were more accurate among the 4 types of IOSs, Primescan, Trios 3, CS3600, and i500. Among the brackets, it should be noted that the polycrystalline ceramic bracket, which has less reflection or absorption of light when using the scan, has high accuracy, and there is more error when using other types of brackets.

Keywords: accuracy, intraoral scanner, orthodontic bracket, precision, trueness

Scanning accuracy of bracket features and slot base angle in different bracket materials by four intraoral scanners

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I. INTRODUCTION

Intraoral scanners (IOS) are used in dentistry as a convenient method of taking impressions (Favero, et al., 2017; Graf, et al., 2017; S. Y. Kim, et al., 2018; Park, et al., 2020; Park, et al., 2019; Yang, et al., 2019). Orthodontic tooth movement can also be easily evaluated using IOS (Sha, et al., 2020; Yoon, et al., 2018). Through the dental model acquired at the time of re-diagnosis of patients undergoing orthodontic treatment, not only the relationship between the entire dentition and the arch, but also the position of the bracket is reevaluated. The placing of straight archwire in preadjusted brackets produce three-dimensional tooth-moving forces as a result of the intimate fit of wire into the bracket slot (Andrews, 1989; Archambault, et al., 2010; Badawi, et al., 2008; Gioka and Eliades, 2004; Morina, et al., 2008). Therefore, during orthodontic treatment, the position, height, torque, and angulation of the bracket are very important components that have a great influence on the treatment outcome. To evaluate whether the bracket prescription is accurately expressed by checking the height, position, and angle of the bracket slot can help to produce a perfect treatment result (Yun, et al., 2018). However, it is not easy to obtain such a record with conventional impression due to undercut of the brackets and wires. Using an IOS may reduce patient discomfort, and more accurate evaluation may be possible in this area. In addition, products such as Suresmile are provided by bending archwire with a robot with data scanned by IOS during treatment (Mah and Sachdeva, 2001). In this case, the angle and position of the bracket slot must be scanned very accurately to enable wire bending and torque (Alford, et al., 2011), but they are already used under the premise that the bracket scan is accurate. Jung et al. (Jung, et al., 2016) reported that when the bracket-attached model and the bracket-wire ligated model were scanned with IOS, they showed a significant difference in accuracy in the horizontal and vertical measurement items compared to the model without the bracket. Park et al. (Park, et al., 2016) reported that the horizontal and vertical measurement of the arch with the lingual bracket showed a significant difference in accuracy compared to the arch with the buccal bracket. However, there is no study on whether the angle and shape of the bracket slot are accurately scanned.

In addition, depending on the material properties, there may be differences in the performance of the IOS. In a study on the effect of the material surface on the scan error of IOS, Kurz et al. (Kurz, et al., 2015) reported that the error was greater in the resin and metal groups than in the ceramic. Song et al. (Song and Kim, 2020) applied artificial saliva to the maxillary model with non-bracket, ceramic, metal, and resin brackets and scanned with CS3600, i500, Trios 3, Omnicam IOSs. In this study, the mean and the maximum discrepancy value were evaluated, and it was confirmed that the discrepancy of the dentition with resin and metal bracket was greater than that of the ceramic bracket. However, because the scan images of the entire maxillary dentition were superimposed to evaluate the discrepancy, the shape of the bracket or the angle of the slot could not be confirmed.

The accuracy of IOS is divided into precision and trueness (ISO5725-1, 1994). The precision refers to the degree to which data acquired by repeating scans under the same conditions match each other. Trueness refers to the ability to reproduce the overall arch close to the real without three-dimensional deformation or distortion.

IOS can be classified into active triangulation, confocal microscopy, optical coherence tomography, and active wavefront sampling according to the data capture principle. Depending on the data capture mode, it can be classified as a system that acquires and stitches individual images or a video sequence system, ultrafast optical sectioning technique. The CS3600 and i500 are scanners using active triangulation. The CS3600 is a video sequence system, and the i500 is a method of stitching images. Trios 3 uses the confocal microscopy principle and ultrafast optical sectioning technique. The recently released Primescan uses a new scanning technique, high frequency contrast analysis and dynamic depth scan. In this study, we studied to confirm whether the four principles show differences in accuracy using different scanners.

The aim of this study was to evaluate the accuracy of digital scan images of brackets produced by four IOSs when scanning the surface of the dental model attached with four different bracket materials. The accuracy was verified for errors in the bracket features and bracket slot angle. The null hypotheses were that there are no differences in scanning accuracy depending on the type of scanners and there are no differences in scanning accuracy depending on the materials.

II. MATERIALS AND METHODS

1. Study model design

Two upper dental study models (Dentiform, Tomy Inc., Fuchushi, Japan) were prepared. The horizontal axis was marked using the 019 x 025 stainless steel wire at the position to attach the bracket on the dentiform, and the vertical axis was marked in advance based on the tooth axis. Brackets were bonded on the buccal side with direct passive bracketing using 019 x 025 stainless steel wire from right second premolar to left second premolar. The brackets used in model A were Bionic metal MBT 022 bracket (Ortho Technology, Lutz, FL, USA) for the right teeth, Reflections ceramic MBT 022 bracket (Ortho Technology, Lutz, FL, USA) for the left teeth and in model B were resin bracket Purfit I resin MBT 022 bracket (US Orthodontic products, Norwalk, CA, USA) for the right teeth, Purfit II resin MBT 022 bracket with metal slot (resinmetal bracket) (US Orthodontic products, Norwalk, CA, USA) for the left teeth. The Purfit II resinmetal bracket had the same design as the Purfit I resin bracket, and only slots are metal (Table 1).

Table 1. Summary of the brackets used for experiments

Material	Model name	Manufacturer	Dimension (inches)	Position	Prescription; torque(°)
Stainless steel	Bionic metal	Ortho Technology, Lutz, FL, USA	022	Model A #11-15	MBT Central incisor; +17° Lateral incisor; +10° Canine; 0°or-7° (Metal, Ceramic; 0°, Resin, Resinmetal; -7°) Premolar; -7°
Polycrystalline alumina	Reflection ceramic	Ortho Technology, Lutz, FL, USA	022	Model A #21-25	
Composite	Purfit l resin	US Orthodontic products, Norwalk, CA, USA	022	Model B #11-15	
Composite, stainless steel slot	Purfit ll resin (resinmetal) ;*same design as the Purfit 1 resin bracket, and only slots are metal)	US Orthodontic products, Norwalk, CA, USA	022	Model B #21-25	

2. Scanning Electron Microscopy

All brackets were analyzed by SEM (S-3000N, Hitachi, Tokyo, Japan). The specimens were mounted on SEM studs and dried with freeze dryer (ES-2030, Hitachi, Tokyo, Japan). Platinum sputtered to a thickness of 100 nm using an ion coater (E-1010, Hitachi, Tokyo, Japan). Photomicrographs at 20 times magnification were taken from the face and both sides of the bracket at an operating voltage of 15 kV. Torque and bracket slot angle of brackets were measured with a computer-based measuring tool (Image-Pro 10, version 10.0.7, Media Cybernetics, Rockville, MD, USA).

A line coincident with the slot reference line on the bracket was drawn (R) (Figure 1). The corners of the base of the bracket slot were round, so a line parallel to the slot base (dotted line) at a distance of 0.1 mm from the slot base was drawn (B). Similarly, a line parallel to the upper wall of the slot at a distance of 0.1mm from the upper wall of the slot was drawn (U) and a line parallel to the lower wall of the slot at a distance of 0.1mm from the lower wall of the slot was drawn (L). The angle formed by lines R and B as the slot base angle (SBA), the angle formed by lines R and U as the upper angle (UA), and the angle formed by lines R and L as the lower angle (LA) were denominated. The difference of SBA was calculated by comparing the SBA measured on each scanned image with the nominal torque provided by the manufacturer (Difference of SBA= |nominal torque-SBA|). The absolute value of the difference between the measured UA and LA (ABS angle= |UA-LA|) was calculated to compare the parallelism of the slot wall. All measurements were performed twice at 30 days intervals to ensure the reliability of the studied data.

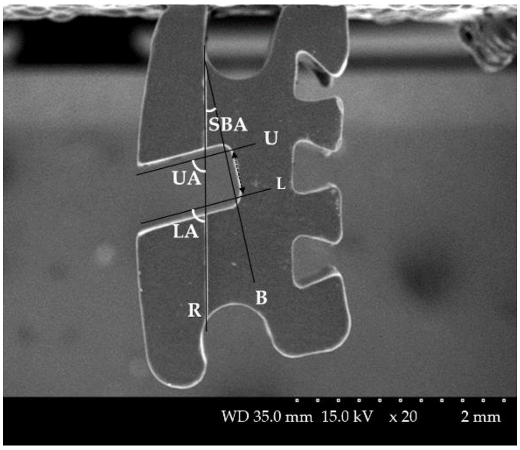


Figure 1. Bracket angles of SEM. Reference line on the bracket: R, A line parallel to the slot base (dotted line) at a distance of 0.1mm from the slot base: B, A line parallel to the upper wall of the slot at a distance of 0.1mm from the upper wall of the slot: U, A line parallel to the lower wall of the slot at a distance of 0.1mm from the lower wall of the slot: L, The angle between R and B: Slot Base Angle (SBA), The angle between R and U: Upper Angle (UA), The angle between R and L: Lower Angle (LA).

3. Scanning process

This study evaluated 4 types of digital intraoral scanners and 1 extraoral scanner as a reference: Trios 3 (3shape, Copenhagen, Denmark), CS3600 (Carestream Dental LLC, Atlanta, GA, USA), Medit i500 (Medit, Seoul, Republic of Korea), Primescan (Dentsply Sirona, York, PA, USA), and E4 (3shape, Copenhagen, Denmark).

Table 2. Intraoral scanners, manufacturer, scanner technology, light source, acqusition method, software version

Product	Manufacturer	Scanner Technology	Light Source	Acqusition Method	Software Version
Primescan	Dentsply Sirona, York, PA, USA	Dynamic depth scan and high frequency contrast analysis	Light	Individual image	5.1
Trios 3	3shape, Copenhagen, Denmark	Confocal microscopy	Light	Ultrafast optical sectioning technique	1.4.7.3
CS3600	Carestream, Atlanta, GA, USA	Triangulation	Light	Video sequence	3.1.0
i500	Medit, Seoul, Republic of Korea	Triangulation	Light	Individual image	2.2.4.7

An extraoral scanner, E4 (E4 Dental Scanner; 3Shape, Copenhagen, Denmark) was calibrated in accordance with the manufacturer's instructions. Study models applied powder and were digitized as the reference model using E4 scanner at a constant room temperature (23 °C) following the manufacturers´ instructions. The manufacturer reports the accuracy of this scanner as 4 μm (Kim, et al., 2019; Nedelcu, et al., 2018; Son and Lee, 2020).

Models were scanned by the one operator using 4 intraoral scanners, according to the manufacturer’s recommendation. No powders were applied to the models during scanning. Four intraoral scanners were used to scan parts with the same type of bracket attached. Scanning was started with 2nd premolar and continued to incisor along the occlusion. First, the occlusal surfaces were scanned and then the lingual and buccal surfaces. When scanning the occlusal surfaces, the scanner head was kept at 0-5 mm from the teeth. For scanning the lingual and buccal surfaces, the scanner tip was rolled 45° to 90° to the lingual and buccal sides, respectively. The image was continuously checked that no areas were missed with the screen.

4. Datasets

All datasets were converted to STL (Stereolithography) files via manufacturers' certified software for standardization. Each study model was scanned parts with the same type of bracket attached, 5 times repeatedly (E4, S1-S5). Each study model was scanned 5 times repeatedly by 4 intraoral scanners (IOS, S1-S5). As a result, 80 IOS datasets were produced in this study.

5. Scan data analysis

5.1 Setting the axis of the bracket

All scanned data processing was performed using the Geomagic control X program (2020.1.0, 3D systems, Rockhill, SC, USA). The axis of the bracket was set based on the tooth axis in order to compare by separating only the brackets. Each image was trimmed just below the gingival line in order to minimize the data size to facilitate analysis and to exclude artifacts in unimportant areas (Vogel, et al., 2015). Each tooth with a bracket attached was separated. The five scan data (S1-S5) were divided into five teeth: central incisor, lateral incisor, canine, 1st premolar, 2nd premolar. The y-axis was set tangent to the labial surface of the tooth and to include the bracket base from the sagittal view. The x-axis was set to be perpendicular to the y-axis, and parallel to the slot at the face of the bracket. The z-axis was set so that the incisal portion of the bracket wing was bisected at the axial view and the bracket slot base was bisected at the sagittal view and perpendicular to the xy plane on the bracket base (Figure 2). The setting of the axial direction was completed by checking the origin of the bisector of the sagittal, front and axial direction of the bracket. In this way, the axis of the bracket and single tooth of E4 S1 scan image were set. The axes were set for each of the 5 separated teeth, and 4 types of bracket materials (metal, ceramic, resin, and resinmetal) were performed in the same way. The remaining 24 scanned images (E4 S2-S5, 4 IOS S1-S5) of the same tooth with the same bracket material were loaded one by one using the E4 S1 image set in the Geomagic control X program as reference data. By using the alignment function between the measured data, the entire optimal alignment was performed and the axis was set equally based on the teeth. The base plane was set as the xy plane, and only the bracket was uniformly divided by the base plane with the z-axis as the normal direction from the origin (Figure 2). Comparison of images of devided brackets was shown Figure 3 and Figure 4.

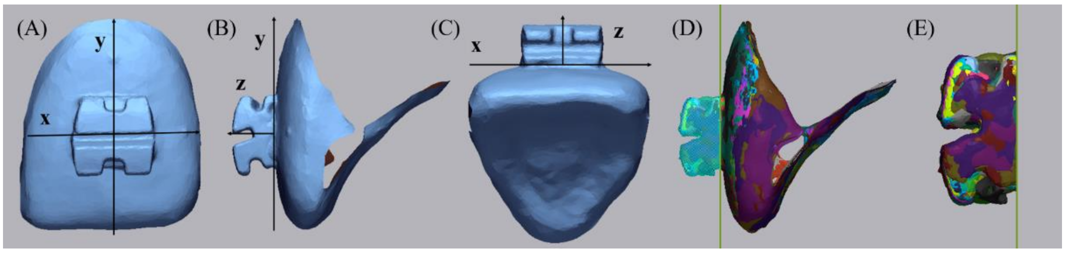


Figure 2. Setting the axis of the bracket. (A,B,C) To include the bracket base and tangent to the labial surface of the tooth from the sagittal view; y-axis, to be perpendicular to the y-axis and parallel to the slot at the face of the bracket; x-axis, to be perpendicular to the xy-axis on the bracket base and bisector of the slot base (sagittal view) and incisal portion of bracket wings (axial view); z-axis. (D) All central incisor meshes for which axis setting has been completed were imported. Only the bracket was uniformly divided by the xy plane with the z-axis as the normal direction from the origin. (E) Divided ceramic brackets.

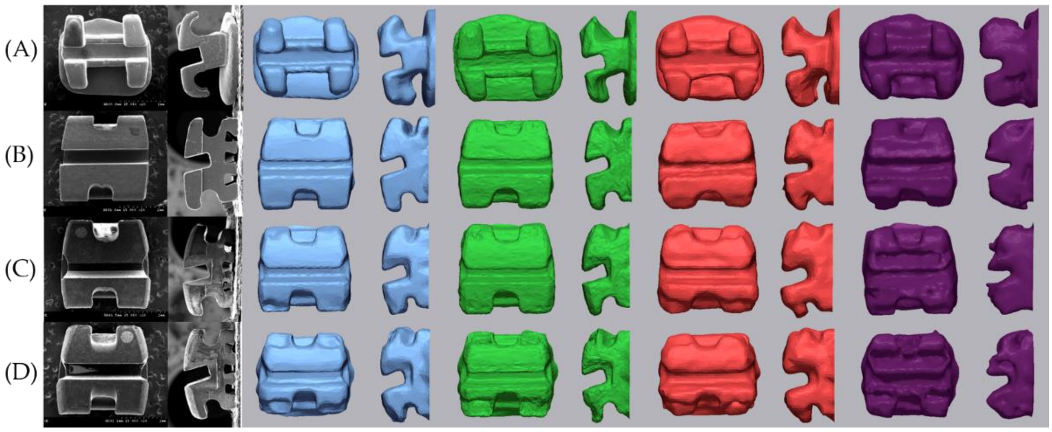


Figure 3. Comparison of images of brackets of central incisor. From left to right: SEM micrographs, Primescan, Trios 3, CS3600, i500. (A) Metal bracket. (B) Ceramic bracket. (C) Resin bracket. (D) Resin bracket with metal slot.

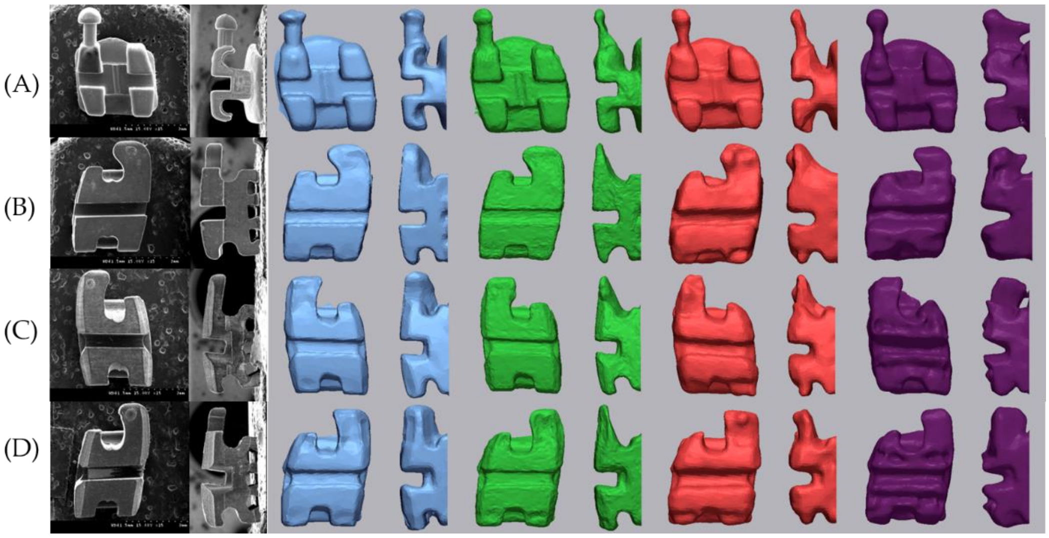
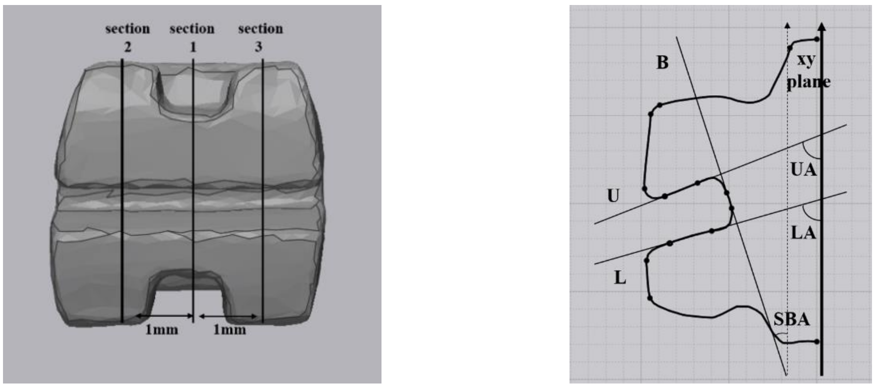


Figure 4. Comparison of images of brackets of canine. From left to right: SEM micrographs, Primescan, Trios 3, CS3600, i500. (A) Metal bracket. (B) Ceramic bracket. (C) Resin bracket. (D) Resin bracket with metal slot.

5.2 Bracket slot angle

Section 1 was formed by cutting the bracket with the yz-plane (Figure 5). Section 2 and section 3 were formed by cutting the brackets at a distance of -1 mm and +1 mm to the x-axis from the yz plane. Similar to Figure 1, in each section, a line was drawn tangent to the bracket slot base (B), its contour was defined as the intersection of two points marked on this wall at a distance of 0.1 mm from the bracket slot wall. Two lines was drawn tangent to the upper wall of the bracket slot (U) and tangent to the lower wall of the bracket slot (L) at a distance of 0.1 mm apart from the slot base and slot face. Depending on the scanner type, when the line angle was more rounded, a line was drawn tangent only with a straight slot wall excluding the round part. On each section, B, U, L lines were drawn in the same way as SEM measurement (Figure 1), and the slot base angle (SBA), upper angle (UA) and lower angle (LA) for the xy plane were measured. The average of the three values measured in sections 1,2,3 was calculated. Difference of SBA (=|nominal torque-slot base angle|) and ABS angle (= |UA-LA|) were calculated.



(A) (B)

Figure 5. Bracket angles of IOS. (A) Sections 1,2, and 3 were formed by cutting the bracket with the yz-plane. (B) Tangent to the bracket slot base: B, Tangent to the upper wall of the bracket slot: U, Tangent to the lower wall of the bracket slot: L, The angle between R and B: SBA, The angle between R and U: UA, The angle between R and L: LA.

5.3 Superimposition

5.3.1 Precision. The precision of the data repeatedly measured 5 times in each IOS was measured by cross-comparison for each bracket. Within each IOS, two brackets were superimposed based on the axis of the bracket. The error between the two brackets in all data point clouds was calculated as the RMS value.

$$RMS = \frac{1}{\sqrt{n}} \cdot \sqrt{\sum_{i=1}^{n} (X_{1,i} - X_{2,i})^2}.$$

X1,i and X2,i is the i point of two brackets of IOS, and n is the number of all measured points. The RMS value shows how far the deviation is from zero between the other two values of the data. So, when the RMS value is low, it indicates that the overlapped data is three-dimensionally consistent. The color range was set to 0-0.2 mm and the result was displayed as a colormap. Primescan, Trios3, CS3600, i500 were all performed.

5.3.2 Trueness. The brackets scanned by the E4 reference scanner and each IOS were superimposed each of two based on the axis of the bracket. The trueness of each IOS was calculated by RMS value and maximum discrepancy value. The color range was set to 0-0.2 mm and the result was displayed as a colormap.

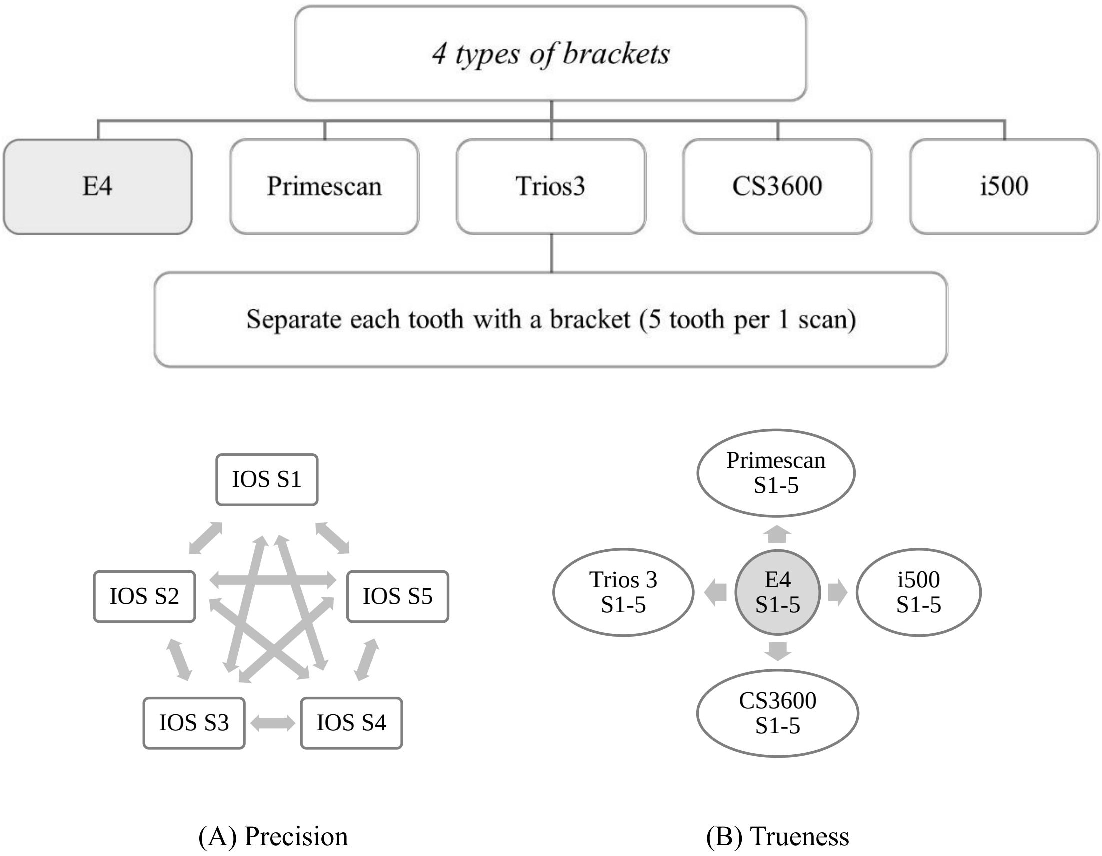


Figure 6. Flow chart of scans with E4 reference scan, intraoral scan for each subject. (A) Cross-comparision for precision. (B) Use of reference for accuracy test. Multiple intra-system scans denoted by S1-S5.

5.3.3 Bracket wing. The superimposed bracket wing was divided into 4 part: upper-mesial, upper-distal (UD), lower-mesial (LM), and lower-distal (LD) to evaluate errors. If there was discrepancy of 20 μm or more in one part, it was set to 1, and if all discrepancies were less than 20 μm, it was set to 0 and the frequency up to 0-4 was evaluated.

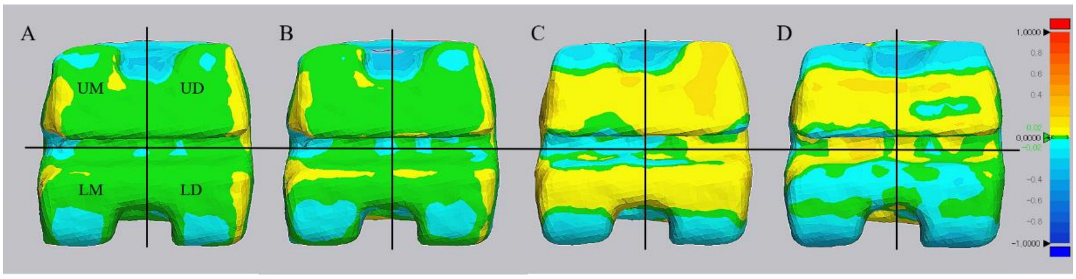


Figure 7. Bracket wing error frequency of ceramic bracket on central incisor. (A) Primescan: 0, all discrepancies were less than 20 μm. (B) Trios 3: 0 (C) CS3600: 4, discrepancy of 20 μm or more in 4 part. (D) i500: 4. UM; upper-mesial, UD; upper-distal, LM; lower-mesial, LD; lower-distal.

6. Statistical analysis

All statistical analyses were performed using IBM SPSS software, version 25.0 (IBM Korea Inc., Seoul, Korea) for Windows. The mean, standard deviation (SD), median and quartile were used to describe the distribution of each variable in this study. When $N \leq 30$, The Kolmogorov-Smirnov test and the Shapiro-Wilk test were carried out to verify the normality of each variable. For total precision RMS, trueness RMS and bracket wing error frequency, one-way analysis of variance (ANOVA) and post-hoc Tukey test were used. The differences of SBA for each tooth were tested by Kruskal-Wallis test, and for all teeth were tested by ANOVA and post-hoc Tukey test. ABS angles were tested by Kruskal-Wallis test and Mann-Whitney U test post-hoc pairwise comparisons. P values less than 0.05 were considered statistically significant.

III. RESULTS

1. Precision (RMS)

The precision was shown in Table 3. As a result of the post-hoc Tukey test, significant differences between IOSs in the same bracket were shown in uppercase letters. In all brackets, the precision was significantly different in the order of Trios 3 < Primescan < CS3600 < i500 (P <0.001). In all IOSs, RMS values were small for metal and ceramic brackets, and significantly larger for resin and resin metal brackets (P <0.01).

Table 3. Precision RMS results from superimposition of IOS scanned images with context interaction in all teeth.

	RMS (Mean ± SD, ㎛)					
Bracket material	**Primescan**	**Trios 3**	**CS3600**	**i500**	**Total**	**P**
Metal	27.15 ± 9.17 ^{Aa}	29.08 ± 4.46 ^{Ab}	53.24 ± 17.62 ^{B}	59.57 ± 12.36 ^{Ca}	42.26 ± 18.67 ^{a}	***
Ceramic	26.88 ± 10.23 ^{Aa}	24.28 ± 4.24 ^{Aa}	54.50 ± 13.30 ^{B}	68.65 ± 18.70 ^{Cb}	43.58 ± 22.62 ^{ab}	***
Resin	39.53 ± 10.80 ^{Bb}	22.79 ± 4.84 ^{Aa}	56.95 ± 14.87 ^{C}	73.93 ± 13.15 ^{Db}	48.30 ± 22.32 ^{b}	***
Resinmetal	39.81 ± 16.82 ^{Bb}	27.39 ± 5.30 ^{Ab}	55.75 ± 13.85 ^{C}	70.43 ± 15.59 ^{Db}	48.34 ± 21.18 ^{b}	***
Total	33.34 ±13.70 ^{B}	25.89 ± 5.31 ^{A}	55.11 ± 14.95 ^{C}	68.14 ± 15.95 ^{D}		***
P	***	***	NS	***	**	

* P <0.05, **P <0.01, *** P <0.001, NS: not significant, P value calculated One-way ANOVA and Tukey's post hoc analysis at α=0.05. ^{A,B,C,D} Uppercase letters within the same row indicate significant differences between scanners. ^{a,b} Lowercase letters within the same column indicate significant differences between brackets.

2. Quantitative analysis of trueness

2.1 RMS

The average and standard deviation of the trueness RMS was shown in Table 4. RMS values were in the order of Trios 3 < Primescan < i500 < CS3600 and there was a significant difference in all brackets (P <0.001). In all scanners, RMS values were in the order of metal bracket < ceramic bracket < resin and resin metal bracket (p <0.001). There was no significant difference between resin and resinmetal bracket.

2.2 Maximum discrepancy

The maximum discrepancy was in the order of Trios 3 < Primescan < CS3600 < i500 in all brackets (P <0.001). In all scanners, the maximum discrepancy was that in order of metal, ceramic < resin, resinmetal (P <0.001).

Table 4. RMS and Maximum Discrepancy of trueness results from superimposition of reference and scanned images in all teeth

	RMS (Mean ± SD, ㎛)					
Bracket material	**Primescan**	**Trios 3**	**CS3600**	**i500**	**Total**	**P**
Metal	85.32 ± 5.75 ^{Ba}	78.54 ± 5.38 ^{Aa}	89.69 ± 5.55 ^{Ca}	85.65 ± 6.89 ^{Ba}	85.05 ± 7.18 ^{a}	***
Ceramic	87.82 ± 4.93 ^{Bb}	85.26 ± 4.93 ^{Ab}	101.36 ± 7.49 ^{Db}	92.73 ± 9.67 ^{Cb}	91.79 ± 9.33 ^{b}	***
Resin	90.78 ± 7.17 ^{Bc}	86.84 ± 5.09 ^{Ab}	107.60 ± 6.44 ^{Dc}	103.64 ± 10.14 ^{Cc}	97.21 ± 11.39 ^{c}	***
Resinmetal	96.09 ± 9.90 ^{Bd}	92.08 ± 6.15 ^{Ac}	102.59 ± 8.68 ^{Cb}	101.77 ± 12.01 ^{Cc}	98.13 ± 10.34 ^{c}	***
Total	90.00 ± 8.21 ^{B}	85.68 ± 7.24 ^{A}	100.31 ± 9.68 ^{D}	96.20 ± 12.00 ^{C}		***
P	***	***	***	***	***	
	Max (Mean ± SD, ㎛)					
Bracket material	**Primescan**	**Trios 3**	**CS3600**	**i500**	**Total**	**P**
Metal	262.64 ± 39.22 ^{ABb}	255.60 ± 34.66 ^{A}	268.70 ± 27.92 ^{BCab}	279.44 ± 30.16 ^{Cab}	267.24 ± 27.47 ^{a}	***
Ceramic	245.18 ± 52.80 ^{Aa}	256.87 ± 46.58 ^{AB}	265.44 ± 37.20 ^{BCa}	276.92 ± 20.80 ^{Ca}	259.30 ± 42.45 ^{a}	***
Resin	273.02 ± 26.01 ^{ABbc}	261.81 ± 57.31 ^{A}	275.21 ± 29.32 ^{Bb}	284.26 ± 33.74 ^{Bab}	274.92 ± 37.83 ^{b}	***
Resinmetal	276.83 ± 17.78 ^{Bc}	256.29 ± 45.34 ^{A}	275.82 ± 16.29 ^{Bb}	288.54 ± 29.43 ^{Cb}	274.38 ± 37.48 ^{b}	***
Total	264.42 ± 38.37 ^{B}	257.64 ± 46.59 ^{A}	271.49 ± 26.94 ^{C}	282.29 ± 29.18 ^{D}		***
P	***	NS	***	**	***	

* P <0.05, **P <0.01, *** P <0.001, NS: not significant, P value calculated One-way ANOVA and Tukey's post hoc analysis at α=0.05. ^{A,B,C,D} Uppercase letters within the same row indicate significant differences between scanners. ^{a,b,c} Lowercase letters within the same column indicate significant differences between brackets.

3. Qualitative analysis of trueness

3.1 Scanning ability of bracket wing

The frequency of error of the bracket wing is shown in Table 5. There was a significant difference in the order of Trios 3 < Primescan < CS3600 < i500 in all brackets (P <0.001). In all scanners, The frequency of error in metal and ceramic were small and resin and resinmetal were large (P <0.001).

Table 5. Scanning ablility of bracket wing results from superimposition of reference and scanned images

Bracket wing error frequency (score 0-5, Mean ± SD)						
Bracket Material	**Primescan**	**Trios 3**	**CS3600**	**i500**	**Total**	**P**
Metal	0.02 ± 0.15 ^{Aa}	0.00 ± 0.00 ^{Aa}	2.02 ± 0.94 ^{Cb}	0.58 ± 0.77 ^{Ba}	0.66 ± 1.02 ^{a}	***
Ceramic	0.02 ± 0.15 ^{Aa}	0.09 ± 0.34 ^{Aa}	1.45 ± 0.83 ^{Ba}	1.62 ± 1.32 ^{Bb}	0.80 ± 1.09 ^{a}	***
Resin	0.74 ± 1.37 ^{Bb}	0.29 ± 0.69 ^{Ab}	2.26 ± 1.12 ^{Cb}	3.59 ± 0.60 ^{Dc}	1.72 ± 1.64 ^{b}	***
Resinmetal	1.09 ± 1.15 ^{Bc}	0.70 ± 0.92 ^{Ac}	2.15 ± 1.30 ^{Cb}	3.51 ± 0.87 ^{Dc}	1.84 ± 1.53 ^{b}	***
Total	0.47 ± 1.01 ^{B}	0.27 ± 0.66 ^{A}	1.97 ± 1.11 ^{C}	2.33 ± 1.58 ^{D}		***
P	***	***	***	***	***	

* P <0.05, **P <0.01, *** P <0.001, NS: not significant, P value calculated One-way ANOVA and Tukey's post hoc analysis at α=0.05. ^{A,B,C,D} Uppercase letters within the same row indicate significant differences between scanners. ^{a,b,c} Lowercase letters within the same column indicate significant differences between brackets.

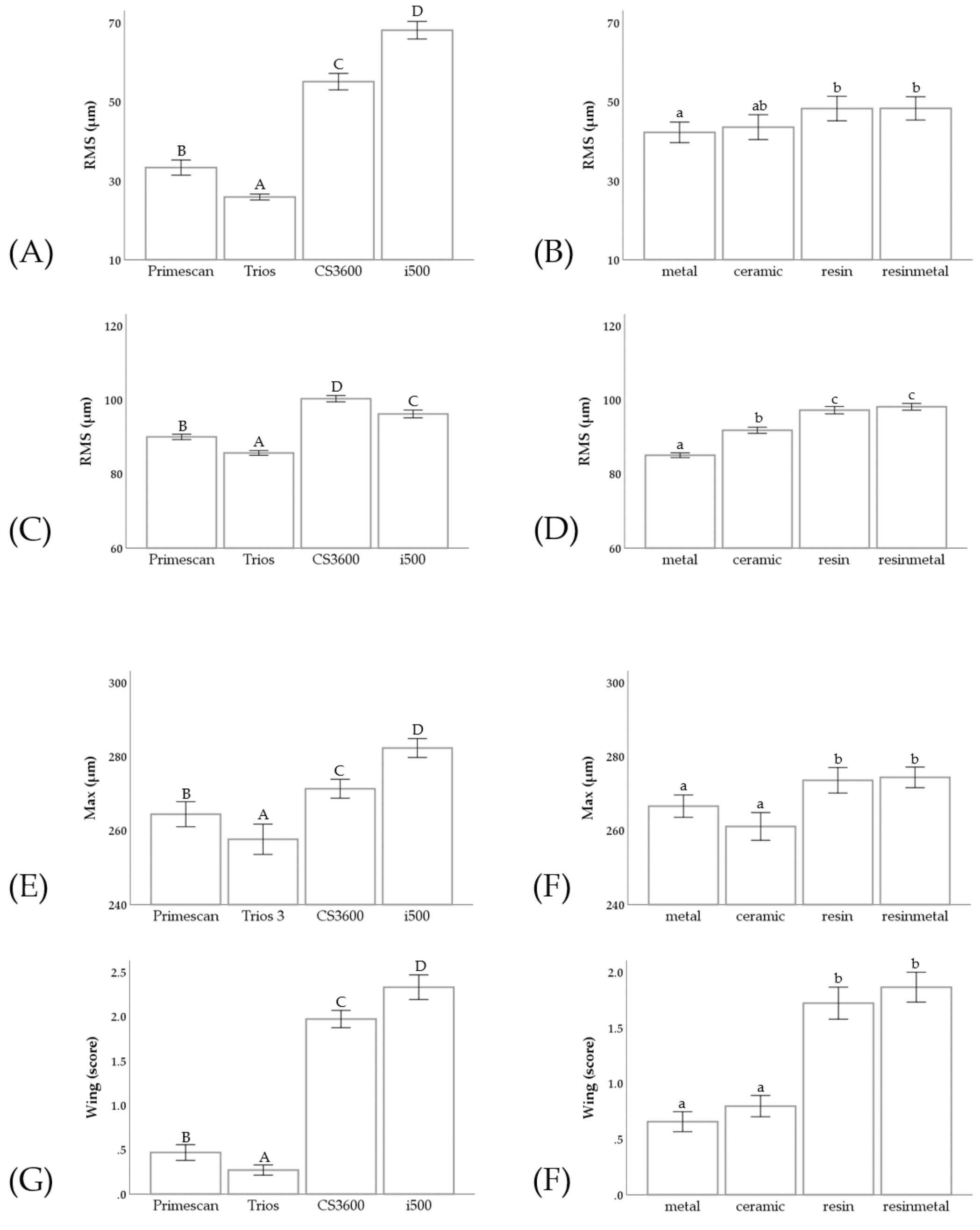


Figure 8. Precision RMS, trueness RMS, maximum discrepancy, bracket wing error frequency

in scanners and brackets (Unit: µm) (A) Precision RMS in scanners. (B) Precision RMS in brackets. (C) Trueness RMS in scanners. (D) Trueness RMS in brackets. (E) Maximum discrepancy in scanners. (F) Maximum discrepancy in brackets. (G) Bracket wing error frequency in scanners. (H) Bracket wing error frequency in brackets. [A,B,C,D] Uppercase letters above the bars indicate significant differences between scanners. [a,b,c,d] Lowercase letters above the bars indicate significant differences between bracket materials.

3.2 Bracket slot

3.2.1 Difference of SBA. The difference of SBA calculated for each tooth were shown in Table 6. i500 was excluded because the slot base was round (Figure 3, 4). There was no significant difference between teeth and brackets, and there was a significant difference between scanners in same tooth. The same trend was observed between scanners in the same bracket. The difference of SBA for all teeth was 0.39 ± 0.31 in SEM, 1.96 ± 0.16 in Primescan, 2.04 ± 1.95 in Trios 3, and 5.21 ± 4.32 in CS3600 (P <0.001). There was no significant difference between Primescan and Trios 3, and there were significant differences in all others.

Table 6. Difference of SBA for each tooth according to the IOS and bracket materials

		Difference of SBA, Median (Q1-Q3), (°)					
	Bracket	**SEM**	**Primescan**	**Trios 3**	**CS3600**	P	IOS
Central incisor	Metal	0.46 (0.08-0.84)	1.00 (0.64-1.81)	2.73 (1.70-3.70)	1.67 (1.12-3.08)	*	P <0.001
	Ceramic	0.31 (0.19-0.72)	0.69 (0.41-0.82)	3.77 (3.37-5.26)	10.97 (6.00-16.69)	*	
	Resin	0.59 (0.18-0.80)	1.30 (0.70-3.80)	0.81 (0.68-2.35)	5.76 (2.45-7.27)	*	
	Resinmetal	0.35 (0.12-0.80)	3.41 (2.31-3.55)	1.04 (0.64-2.53)	3.61 (3.30-4.92)	*	
	Total	0.45 ± 0.33 ^{A}	1.64 ± 1.19 ^{AB}	2.57 ± 1.54 ^{B}	4.87 ± 4.54 ^{D}		
	P	NS	*	*	*		
Lateral incisor	Metal	0.44 (0.29-0.80)	6.31 (4.85-7.28)	6.11 (4.80-8.66)	8.28 (4.98-10.68)	*	P <0.001
	Ceramic	0.20 (0.04-0.35)	1.29 (0.82-1.66)	0.69 (0.45-3.47)	2.93 (0.86-3.79)	NS	
	Resin	0.35 (0.11-0.62)	1.45 (0.29-2.12)	0.48 (0.23-0.99)	1.47 (0.53-5.47)	NS	
	Resinmetal	0.92 (0.59-1.64)	1.46 (0.44-5.97)	2.88 (2.62-3.74)	1.85 (0.72-3.82)	NS	
	Total	0.53 ± 0.46 ^{A}	3.53 ± 2.77 ^{B}	3.74 ± 2.99 ^{B}	4.03 ± 0.81 ^{C}		
	P	NS	*	**	*		

Canine	Metal	0.39 (0.32-0.47)	2.11 (1.04-3.43)	1.18 (0.53-2.88)	4.06 (1.50-6.48)	*	P <0.001
	Ceramic	0.16 (0.03-0.32)	3.84 (1.64-4.87)	1.69 (1.10-3.59)	12.76 (4.60-17.79)	*	
	Resin	0.38 (0.06-0.70)	1.54 (0.53-2.67)	0.71 (0.06-1.33)	4.67 (3.17-5.95)	*	
	Resinmetal	0.28 (0.13-0.75)	2.09 (0.74-4.74)	2.83 (1.50-3.69)	6.18 (2.07-6.91)	*	
	Total	0.33 ± 0.25 ^{A}	2.56 ± 1.50 ^{B}	1.74 ± 1.33 ^{B}	5.85 ± 4.55 ^{C}		
	P	NS	NS	NS	NS		
1st Premolar	Metal	0.35 (0.24-0.45)	0.90 (0.82-1.11)	1.45 (1.11-2.04)	4.49 (2.41-5.63)	***	P <0.001
	Ceramic	0.14 (0.05-0.17)	0.54 (0.19-1.06)	0.66 (0.30-0.92)	6.16 (5.80-10.10)	*	
	Resin	0.44 (0.29-0.63)	0.53 (0.34-0.68)	0.39 (0.20-0.61)	1.47 (0.78-4.76)	*	
	Resinmetal	0.29 (0.14-0.56)	0.58 (0.20-1.30)	0.59 (0.52-1.27)	8.00 (4.58-11.54)	*	
	Total	0.31 ± 0.19 ^{A}	0.74 ± 0.40 ^{B}	1.01 ± 0.68 ^{B}	5.23 ± 3.40 ^{C}	*	
	P	NS	NS	*	*		
2nd Premolar	Metal	0.31 (0.10-0.77)	2.61 (1.47-2.89)	1.80 (1.03-2.30)	2.80 (0.78-4.52)	*	P <0.001
	Ceramic	0.32 (0.13-0.43)	0.77 (0.51-1.22)	0.40 (0.19-0.83)	6.48 (6.36-9.46)	*	
	Resin	0.27 (0.18-0.48)	1.02 (0.12-1.39)	0.47 (0.21-1.05)	5.39 (1.48-7.68)	*	
	Resinmetal	0.28 (0.13-0.75)	1.47 (0.50-2.85)	1.35 (0.80-1.79)	5.55 (3.02-16.01)	*	
	Total	0.35 ± 0.25 ^{A}	1.55 ± 1.03 ^{B}	1.15 ± 0.84 ^{B}	5.40 ± 5.16 ^{C}		
	P	NS	*	*	NS		
All teeth		0.39 ± 0.31 ^{A}	1.96 ± 0.16 ^{B}	2.04 ± 1.95 ^{B}	5.21 ± 4.32 ^{C}		

* $P < 0.05$, *** $P < 0.001$, NS: not significant, P value for each tooth calculated with Kruskal-Wallis test. ^{A,B,C} Uppercase letters within the same row indicate significant differences between scanners by Mann-Whitney U test post hoc pairwise comparisons at $\alpha = 0.0083$. P value for all teeth calculated with One-way ANOVA. ^{A,B,C} Uppercase letters within the same row indicate significant differences between scanners by Tukey's post hoc analysis at $\alpha = 0.05$.

3.2.2 ABS angle. The upper angle and lower angle of the bracket slot were shown in Figure 9. The lower angle had less error than the upper angle. The ABS angle was calculated as the absolute value of the difference between the upper and lower angle and showed the parallelism of the slot. Calculated discrepancies were compared with those measured in SEM (Table 7). The mean of the ABS angle was 0.48 ± 0.29 in SEM, 7.00 ± 7.08 in Primescan, 5.52 ± 5.37 in Trios 3, 6.34 ± 5.40 in CS3600, and 23.74 ± 10.02 in i500 ($P < 0.001$). In other words, the parallelism of the bracket slot wall was not significantly different between Primescan, and Trios 3, CS3600. They had significantly greater difference than SEM, and i500 was significantly greater than them. There was no significant difference for error according to the bracket materials.

Table 7. Mean ABS angle and its standard deviation according to the IOSs and bracket materials

	ABS angle (Mean ± SD, °)						
Bracket material	**SEM**	**Primescan**	**Trios 3**	**CS3600**	**i500**	**Total**	**P**
Metal	0.44 ± 0.25 ^{A}	2.99 ± 3.76 ^{Ba}	3.46 ± 3.39 ^{Ba}	5.60 ± 4.79 ^{B}	18.60 ± 8.81 ^{Ca}	7.01 ± 8.36 ^{a}	***
Ceramic	0.52 ± 0.25 ^{A}	6.39 ± 4.71 ^{Bb}	5.94 ± 5.79 ^{Bab}	6.62 ± 5.38 ^{B}	30.11 ± 8.51 ^{Cb}	10.31 ± 11.84 ^{b}	***
Resin	0.34 ± 0.17 ^{A}	5.76 ± 6.08 ^{Bab}	6.07 ± 5.48 ^{Bab}	5.30 ± 5.72 ^{B}	27.63 ± 11.62 ^{Cb}	9.37 ± 11.82 ^{ab}	***
Resinmetal	0.62 ± 0.37 ^{A}	16.95 ± 5.70 ^{Cc}	8.65 ± 6.50 ^{Bb}	8.59 ± 5.88 ^{B}	23.76 ± 6.29 ^{Dab}	12.18 ± 9.53 ^{b}	***
Total	0.48 ± 0.29 ^{A}	7.00 ± 7.08 ^{B}	5.52 ± 5.37 ^{B}	6.34 ± 5.40 ^{B}	23.74 ± 10.02 ^{C}		***
P	NS	***	**	NS	***	***	

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, NS: not significant, P value for Total row and column calculated with One-way ANOVA. ^{A,B,C} Uppercase letters within the same row indicate significant differences between scanners and ^{a,b,c,d} lowercase letters within the same column indicate significant differences between brackets by Tukey's post hoc analysis at $\alpha=0.05$. P value for the others calculated with Kruskal-Wallis test. ^{A,B,C,D} Uppercase letters within the same row indicate significant differences between scanners by Mann-Whitney U test post hoc pairwise comparisons at $\alpha=0.005$, ^{a,b,c,d} lowercase letters within the same column indicate significant differences between brackets by Mann-Whitney U test post hoc pairwise comparisons at $\alpha=0.0083$.

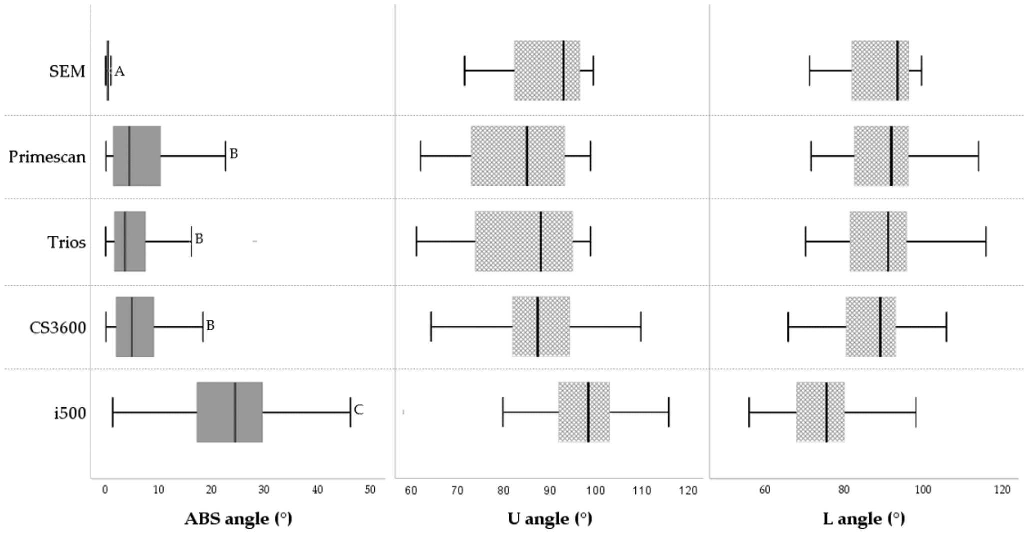


Figure 9. Parallelism of the bracket slot wall. ABS angle represents the parallelism between the upper and lower walls of the bracket slot. [A,B,C] Uppercase letters beside the bars indicate significant differences between scanners.

Ⅳ. DISCUSSION

This study evaluated the performance of 4 types of IOS by limiting it to the bracket scanning images. In this study, there were significant differences in the precision and trueness values of the 4 different bracket materials. In the RMS value of precision and trueness, the metal bracket was similar to or smaller than the ceramic bracket. It is thought that the error was relatively small because the size of the bracket was much smaller than that of the resin or ceramic bracket. Therefore, the maximum discrepancy according to the bracket material is a more meaningful value because the quality of the scanned image may deteriorate and clinical defects may occur if the maximum deviation appears in an important part of the image (Song and Kim, 2020). The maximum discrepancy according to the bracket material was the smallest in ceramic, followed by metal, resin and resinmetal. In the qualitative analysis, the scan accuracy of the bracket wing was lower in resin and resinmetal than in ceramic and metal.

The translucency of the material may have contributed to this result given the effect of the bracket within the same scanner. Kurtz et al. said that when scanning with the triangulation principle IOS, the discrepancy between the metal and the resin material was higher, but the scan noise according to the material type was within the range of the measurement error existing in the conventional impression, so it could be clinically acceptable. However, especially in the presence of water, the error was much larger than the measurement error according to the material, and clinically relevant errors occurred. This was because the deviation of the angle measurement increased due to the refraction of light in water during scanning (Kurz, et al., 2015). Li et al. (Li, et al., 2017) reported that objects with higher translucency objects resulted in lower scanning accuracy and larger morphological changes when scanned with IOS using the confocal microscopy principle. The ceramic bracket was more accurate than the resin, which seems to be because the polycrystalline ceramic bracket used in this study has less light reflectivity. Song et al. stated that the largest discrepancy was in the order of resin> metal> ceramic bracket, which is consistent with the results of this study (Song and Kim, 2020).

Bracket slot angle was divided into SBA (slot base angle) and wall parallelism. For bracket angle measurements (torque and parallelism) according to ISO 27020:2010 (ISO27020, 2010), a manufacturing error of ±1 is permitted. Regarding the parallelism of the inner wall of the slot, Major et al. measured the manufacturing tolerance of the orthodontic bracket slot and reported a convergent taper of 1.47°, a slightly divergent taper below that, and the most rectangle in shape depending on the product (Major, et al., 2010). Araujo et al. reported that there was no significant difference in torque manufacturing tolerance (Araujo, et al., 2019; Gioka and Eliades, 2004; Sebanc, et al., 1984; Siatkowski, 1999), and that it converged with respect to the parallelism of the inner wall of the bracket slot, and that the average parallelism was measured from +0.19 to -4.10 depending on the manufacturer. In this study, the slot base angle was the same as the torque of the bracket prescription, and in order to check the tolerance according to the manufacturer, the torque and parallelism of the actual bracket were measured with a scanning electron microscope, and it was confirmed that it was within the manufacturing error.

When comparing the absolute difference between the nominal torque and the measured SBA, there was a significant difference between scanners. The mean of the differences was 0.39 in SEM, 1.96 in Primescan, 2.04 in Trios 3, and 5.21 in CS3600. Since there may be differences due to the SEM image and the baseline of the IOS, it is desirable to focus on the trend rather than the numerical value. The mean difference of bracket slot wall was 0.48 in SEM, 7.00 in Primescan, 5.52 in Trios

3, 6.34 in CS3600, and 23.74 in i500. The difference in parallelism of the slot wall is large in IOS compared to SEM. There was no significant difference between Primescan, Trios 3 and CS3600, and Primescan and Trios 3 tended to converge, while CS3600 and i500 tended to diverge. Compared with SEM, the mean discrepancy of the upper angle was larger than that of the lower angle. The difference of SBA and ABS angle did not show a tendency according to the bracket material. The deviation of the digital scan is smallest when the IOS camera is positioned perpendicular to the surface to be scanned and the light is reflected at 90 degrees, and the magnitude of the deviation increases as the camera moves away from the vertical plane (Kurz, et al., 2015). Therefore, the reason why the parallelism of the slot wall is more inaccurate than the slot base angle is thought to be that light is farther away from the vertical plane of the camera from the wall than the slot base. In addition, the scan noise of the material caused by reflection or absorption of light exists within the measurement error range. However, it seems that the error due to the bracket material was not confirmed at the slot angle because a larger error occurs in areas where light does not reach well during digital scanning. Also, there was a difference in the roundness of the line angle of the inner surface where the wall of the slot and the base meet according to the type of scanner (figure 3 and 4).

In the case of a bracket that is much smaller than that of an intraoral prepared tooth or implant scan body, the difference in scanning accuracy for errors in slot base or line angle seems to be due to the difference in the principle of the IOS (Arezoobakhsh, et al., 2020; Richert, et al., 2017; Taneva, et al., 2015). The CS3600 and i500 use the principle of triangulation. The CS3600, a video sequence system, scanned the bracket a little more accurately than the i500, which stitches images (Imburgia, et al., 2017; R. J.-Y. Kim, et al., 2018). In addition, Trios 3, which uses the principle of confocal microscopy and ultrafast optical sectioning technique, had higher bracket scanning accuracy than these. It is thought that this was because the depth of field was well expressed by the vibration, so that small structures could be accurately scanned. Primescan also showed high accuracy, and the manufacturer describes that Primescan uses high-frequency contrast analysis and dynamic depth scan as a new method of scanning principle. This is thought to be a similar method to confocal microscopy (Kim, et al., 2021). However, little is known about the various scanning strategies as this aspect has not been clearly explained (Latham, et al., 2020; Mangano, et al., 2017; Mangano, et al., 2020).

This study has several limitations. Since this study is an in vitro study, it does not reflect the conditions with moisture or scan restrictions. Previous studies have shown that the presence of moisture in oral scanners affects the accuracy of the scanner (Park, et al., 2018). This study is a segmentation study that scans from the unilateral central incisor to the second premolar using the maxillary model, and there may be differences in the case of continuous arch. In addition, since the brackets used in this study do not represent many types of brackets, they need to be extended to more types and numbers of brackets. Even if the IOS is the same product, the accuracy may vary depending on the software version. For the i500, this experiment was performed in version 2.2 and the latest software version is currently released up to 2.3.4. According to the manufacturer, there was a firmware upgrade that speeds up scanning and improves shooting capability in metal, so the product using the new version may show different results from this study. Therefore, further research is needed taking this into account.

Ⅴ. CONCLUSION

In this study, we investigated the accuracy of digital scan images of brackets produced by 4 IOSs when scanning the surface of dental model attached with different bracket materials (metal, ceramic, resin, resin bracket with metal slot) by separating only the brackets. For accuracy, the overall shape of the bracket and the slot angle of the bracket were evaluated.

1. There were significant differences in the scanning accuracy of the bracket according to the type of scanner. Precision and trueness were similarly high for Primescan and Trios 3, followed by CS3600 and i500.

2. There was a significant difference in the scanning accuracy of the bracket according to the type of brackets. The maximum discrepancy of the metal was greater than that of the polycrystalline ceramic bracket, and the bracket that transmitted light and translucent like a resin bracket or a resin bracket with a metal slot tended to show the greatest maximum discrepancy.

3. The slot base angle was relatively accurate in Primescan and Trios 3 compared to SEM images, and the accuracy of slot base angle in CS3600 was lower than Primescan and Trios 3. The i500 was scanned round and the slot angle could not be determined.

4. Compared to SEM images, the errors of Primescan, Trios 3, and CS3600 were similarly large for the parallelism of the slot, and the error was very large for the i500.

In this study, as a result of evaluating the performance of four IOSs limited to the bracket scan, there was a significant difference in the precision and trueness values of the four IOSs, and there were significant differences in the precision and trueness values of the four different bracket materials. Therefore, both null hypotheses were rejected.

This study evaluated the accuracy of the bracket only. According to the results of this study, it was possible to confirm the bracket slot base angle, which is difficult to obtain by the conventional impression method according to the scanner type. However, it must be admitted that there is some error in recognizing slots through scanning in general. Considering only the scan of the bracket in this study, Primescan and Trios 3 were more accurate among the 4 types of IOSs, Primescan, Trios 3, CS3600, and i500. Among the brackets, it should be noted that the polycrystalline ceramic bracket, which has less reflection or absorption of light when using the scan, has high accuracy, and there is more error when using other types of brackets.

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국문 요약

교정용 브라켓의 형태와 슬롯 각도에 대한

구강스캐너의 정확성 평가

(지도: 황충주 교수)

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신선희

브라켓 슬롯의 높이와 위치, 각도 등을 확인하여 처방된 브라켓이 잘 발현되고 있는 지 평가하는 것은 좋은 치료 결과를 이끌어내는데 도움이 될 수 있다. 구강스캐너를 이용하면 이러한 교정적 치아이동을 쉽게 평가할 수 있다. 이 연구의 목적은 4 종류의 다른 브라켓 재료(metal, ceramic, resin, resin bracket with metal slot)가 붙어있는 치아모형의 표면을 4 종류의 구강스캐너 (Primescan, Trios 3, CS3600, i500) 로 스캔하여 생성된 디지털 스캔 이미지의 정확도를 평가하는 것이다.

레퍼런스 스캐너로 스캔한 이미지와 주사전자현미경 사진을 기준으로 사용하였다. 레퍼런스 이미지에서 각 브라켓 축을 설정하고 구강스캐너 이미지와 중첩하여 동일하게 축을 설정한 후, 브라켓만 분할하여 정량적, 정성적 분석을 시행하였다. 본 연구의 결과는 다음과 같다.

1. 스캐너의 종류에 따라 브라켓의 스캐닝 정확도에 유의한 차이가 있었다. 정량적 분석에서 Precision RMS는 Trios 3가 가장 작았고, Primescan, CS3600, i500 순으로 커졌다 ($P < 0.001$). Trueness RMS는 Trios 3가 가장 작았고, Primescan, i500, CS3600 순으로 커졌다 ($P < 0.001$). 최대오차는 Trios 3가 가장 작았고, Primescan, CS3600, i500 순으로 커졌다 ($P < 0.001$).

2. 브라켓의 종류에 따라 브라켓의 스캐닝 정확도에 유의한 차이가 있었다. 정성적 분석에서 브라켓 윙의 스캔 정확도는 Trios 3가 가장 작았고, Primescan, CS3600, i500 순으로 커졌다 ($P < 0.001$). 슬롯 벽의 상방 각과 하방 각의 차이로 본 평행도는 SEM에서 0.48, Primescan에서 7.00, Trios3에서 5.52, CS3600에서 6.34, i500에서 23.74 이었다 ($P < 0.001$). 제조사 측의 토크와 브라켓 슬롯 베이스 각도의 오차는 SEM에서 0.39, Primescan에서 1.96, Trios에서 2.04, CS3600에서 5.21로 유의차가 있었다 ($P < 0.001$).

3. 브라켓 재료에 따른 최대 오차는 세라믹이 가장 작았고 다음으로 메탈, 레진과 메탈슬롯이 있는 레진 브라켓 순이었다. ($P < 0.05$) 정성적 분석에서 브라켓 윙의 스캔 정확도는 세라믹과 메탈보다 레진과 레진메탈 브라켓이 낮았다 ($P < 0.05$). 레진이나 메탈 슬롯이 있는 레진 브라켓처럼 더 반투명하여 빛을 투과하는 브라켓이 메탈이나 다결정 세라믹 브라켓보다 더 큰 오차를 나타내는 경향이 있었다.

이 연구는 브라켓에 국한하여 정확도를 확인하였고 본 연구의 결과에 따르면, 스캐너 종류에 따라 기존 인상법으로 채득하기 힘든 브라켓 슬롯 베이스 각도를 확인할 수 있었다. 그러나 일반적으로 스캔을 통해 슬롯을 인식하는 것이 어느 정도의 오차가 있다는 것을 인

정해야 한다. 이 연구에서 브라켓의 스캔만을 고려하였을 때, Primescan, Trios 3, CS3600, i500 4 종류의 IOS 중에는 Primescan과 Trios 3가 정확도가 높은 편이었다. 브라켓 중에서 스캔을 사용할 때는 빛의 반사나 흡수가 적은 다결정 세라믹 브라켓이 오차가 적었으며, 레진 브라켓, 메탈 브라켓, 메탈 슬롯이 있는 레진 브라켓을 사용할 때는 오차가 더 있음을 고려해야 한다.

핵심이 되는 말: 정확도, 구강스캐너, 교정용 브라켓, 정밀도, 진도