Verification of evaluation system for occlusal facets on sleep splint

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Abstract: Purpose: This study aimed to verify the thickness detectability of our evaluation system using a dental scanner (D900) for the occlusal facets on sleep splints.

Materials and Methods: First, the accuracy of the D900 was investigated via a multi sphere test. Surface roughness, diameter, and distances among centers in three SUJ2 stainless spheres were investigated. Then, the thickness detectability of our evaluation system was investigated using gauge blocks. The ceramic gauge blocks were located on a flat stone board, and then were scanned and superimposed on a flat-surface CAD model used as a reference plane. The distance between the scanned surface of each gauge block and the reference plane were calculated. Finally, to evaluate the performance of our system in a clinical setting, a 35-year-old female volunteer who was aware of sleep bruxism was recruited. The differences in vertical heights between images of two models (before and after applying the splint) were investigated.

Result: The relative errors of diameter (0.154%) were significantly bigger than that of distance among three spheres (0.01%) because of powder coating. The D900 can produce high accuracy 3D scanning if powder coating is not required, completely distinguish the thickness difference of 10 μm of gauge block. As our evaluation system detects changes in the splint surface by comparing surface profile between two stone model before and after splint wearing, it is considered that the minimum detectable thickness of our system is approximately 50 μm, because it is affected by the surface roughness of both two stone model. Not only the wear facet on splint but also the deformation of splint was caused by excessive occlusal force after 14days applying. It was considered that the palate region was an appropriate region of interest (ROI) for registration to evaluate the whole deformation and fit of the splint. To evaluate the occlusal facets, the surface of the splint region was an appropriate ROI. We were able to detect the occlusal facets using our evaluation system.

Conclusion: It was revealed that our system can detect differences of approximately 50 μm in thickness. It was suggested the appropriate ROI for registration should be selected depending on analytical parameters. Our system can detect the occlusal facets on the surface of splint after 14days applying.
I. Introduction

Nocturnal bruxism is an important risk factor influencing the prognosis of prosthesis\(^1\). Therefore, after prosthodontic treatment, the occlusal splint is applied to avoid overloading of the abutment teeth and the prosthesis due to bruxism. Splint therapy can be an important diagnostic tool to determine wear patterns, bruxism, and temporomandibular disorder status. Generally, the occlusal stabilization splint is used to achieve these purposes. The wear facets due to bruxism are observed on the occlusal surface of the splints. In addition, when the splint is not applied, the excessive occlusal force develops the wear facets exist on the splint are occurred on the natural dentition. Information gained from wear patterns on the splints helps determine occlusal configurations, material choice, cusp heights and shapes, guidance angulations, axial loads, and the envelope of function\(^2\).

In 1993, Holmgren et al.\(^3\) observed the active shine faces due to nocturnal bruxism on the occlusal splint. They reported a repetitive wear pattern on the occlusal splint, and they concluded that the occlusal splint does not stop the habit of nocturnal bruxism. Active wear facets on the splint were observed in 61% of the patients at every visit, in 39% from time to time. In 1998, Korioth et al.\(^4\) digitized and analyzed the stabilization splint after three months of wear. They reported that parafunctional nocturnal dental activity on full-arch occlusal stabilization splints resulted in asymmetric and uneven wear. In five subjects the wear depth ranged from 21 μm to 540 μm. However, some researchers had their doubt about these findings because confirmation of the reliability of the methods had not been reported\(^5\). To detect the occlusal facets, the evaluation system using a 3D scanner should have the appropriate level of measurement accuracy. In our previous study, we also digitized and analyzed the original sleep splint, and investigated the relationship between the nocturnal muscle activity and the degree of facets on the splint\(^6\). In this current study, we would verify the reliability of our system in detail.

Fig. 1 shows the procedure for evaluating the occlusal facets on the splint using our devised system includes a dental 3D scanner (D900, 3Shape A/S, Copenhagen, Denmark). In this process, several errors may influence the accuracy of our evaluation system. Accuracy consists of precision and trueness\(^7\). “Precision” refers to the closeness of agreement between test results. “Trueness” refers to the closeness of agreement between the arithmetic mean of a large number of test results and the true or accepted reference value. The methods for evaluating trueness include scanning calibrated objects with known dimensions, such as, a sphere or a block.\(^8\) First, we investigated the accuracy of the dental 3D scanner via a multi sphere test. Then, the minimum depth detectability was investigated using gauge blocks. Finally, to assess the clinical use of our system, a 35-year-old female volunteer who was aware of sleep bruxism was recruited.

The aim of this study was to verify the performance of our evaluation system for occlusal facets on the sleep splint.

II. Materials and Methods

1. Volumetric analysis via multi spheres test

Figure 2 shows the specimen for analysis. A volumetric accuracy test was performed by scanning an upper dentition model with attached six spheres made of SUJ2 (high-carbon chromium bearing steel in conformity with JIS G 4805) with a nominal diameter of 10.0 mm (Grade G10, Amatsuji steel ball, Amatsuji Co., Osaka, Japan). In this current study, the three spheres located in the dentition (UA1, UB1, and UC1) were measured. The spheres were located in the incisal region (UC1) and both sides of the first molar regions (right: UA1, left: UB1). To obtain the reference data, the specimen was measured by a high accuracy contact-type coordinate measuring machine (MICROCORD FN503, Mitutoyo Co., Kanagawa, Japan) that guarantees a maximum permissible length measurement of (4 ± 5L/1000) μm (L=Measuring length in mm). To obtain the experimental data sets, the specimen was scanned 10 times using the D900 after powder
coating. To evaluate the surface roughness and diameter, the scanned data of the UC1 was used and the best approximation surface for sphere used as the reference surface (sphere) was designed with iterative closest point algorithm. The variations in the radial height of the surface of scanned sphere relative to the reference surface were obtained, and the maximum surface peak height and maximum surface valley depth were determined. To evaluate distances among centers in three spheres, all scanned spheres were recruited.

The scanned model was analyzed using 3D image analysis software (Rapidform 2006, INUS Technology, Inc., Seoul, South Korea). The following three parameters were investigated (Fig. 3).

A) sphere shape error (surface roughness): this error shows shape deviations. The difference of maximum surface peak radial height value (positive value) and maximum surface valley radial depth value (negative value) relative to the reference sphere is calculated.

B) sphere size error (diameter): this error shows deviation of the best fitted sphere size. The diameter error is calculated as a difference between the scanned and reference sphere diameter.

C) sphere spacing error (distance): this error shows spacing deviation of the two spheres’ center. The spacing error is calculated as a difference between the scanned and reference distance.

A Steel-Dwass test was performed to compare the relative error between the sphere size and sphere spacing. Statistical analysis was performed with IBM SDSS Statics Ver 22 with significance level at p < 0.05.

2. Thickness detectability

Figure 4 shows the process of investigation of thickness detectability. Six ceramic gauge blocks (Grade K, Mitutoyo Co., Kanagawa, Japan) placed on a flat stone board (depth*width*height: 720*820*10 mm) made of super-hard stone (New Fujirock; GC Corp, Tokyo, Japan). Four of the six gauge blocks (GB1, GB2, GB3, and GB4) were chosen, and used to verify the thickness detectability of our system. Their nominal values were 1.00, 1.01, 1.05, and 1.10 mm respectively. They were scanned three times using the D900. For analysis, three datasets were recruited and analyzed with the following methods. The scanned data was superimposed on a rectangular flat-surface CAD model (depth*width: 720*820 mm) designed using the 3D image analysis software with iterative closest point algorithm. The stone board portion of the scanned data was selected as region of interest (ROI) for registration.
After registration, two analytical regions were selected (Fig. 5). The variations in the vertical height of the scanned surface of the stone board and gauge blocks relative to the reference plane (flat-surface CAD model) within analytical regions were obtained to investigate the surface roughness of the stone board and gauge blocks. Additionally, the distance between the scanned surface of each gauge block and the reference plane was calculated and the absolute and relative errors were obtained to investigate the minimum detectability depth of the D900.

### 3. Clinical application

To evaluate the performance of our evaluation system in clinical setting, a 35-year-old female volunteer who was aware of sleep bruxism was recruited. She had an individual normal occlusion and no missing teeth. The loss of enamel exposing dentine was observed on all canine tips. She had no history of any temporomandibular disorders, such as pain, sound, nor opening limitation. No morbid findings appeared on the X-ray images. This research was approved by the Ethical Committee at Tsurumi University Dental Hospital (Approval No. 1416).

The fabrication and analysis of the sleep splint was performed in accordance with our previous study. The impressions of the volunteer’s upper and lower dentitions were taken for fabrication of an occlusal splint. The two-layered splint was fabricated with the base splint (a polyester sheet with a 0.75 mm thickness; DURAN, Scheu Dental Technology, Iserlohn, Germany) and soft resin (Facet resin, GC, Tokyo, Japan), with approximately thickness of 2 mm in the molar region. The splint was adjusted on the semi-adjustable articulator and applied to the subject after a slight intraoral adjustment. The splint before wearing was placed on the cast and an impression was taken for the first analytical model (Model1). The volunteer was then carefully instructed on how to wear the occlusal splint, and used it for 14 nights.

After 14 days of wearing, the splint was put back to the cast and an impression was taken for the second analytical model (Model2). The analytical models were made of a high strength dental stone (New Fujirock; GC Corp, Tokyo, Japan). These models were scanned and the registration of two scanned data sets was performed in two ROIs (palate and surface of splint) using 3D image analysis software (Rapidform 2006). The differences in vertical height between images of two models were calculated and displayed in different colors.

### III. Results

#### 1. Volumetric analysis via multi spheres test

Table 1 shows the result of sphere shape error (surface roughness) in the multi spheres test. As a result of analysis of the reference dataset, the surface roughness of the sphere was 7.98 \( \mu m \), and more than 95% of the measurement surface (2S.D.) was within \( \pm 2 \mu m \) from the reference surface. On the other hand, the experimental value of surface roughness (mean ± S.D.) was 53.92 ± 9.63 \( \mu m \), and more than 95% of the measurement surface (2S.D.) was within \( \pm 10 \mu m \) from the reference surface.

The results of sphere size and spacing errors (diameter and distance) are listed in the Table 2. The reference value of diameter of the UC1 was 9.993 \( \mu m \). The reference values of distances among spheres (UC1-UA1, UC1-UB1, and UA1-UB1) were 37.349, 37.112, and 48.428 \( \mu m \), respectively. The experimental value of diameter (mean ± S.D.) was 9.997 ± 0.021 mm. The experimental values of distances among
spheres (mean ± S.D.) were 37.349 ± 0.004 mm, 37.112 ± 0.002 mm, and 48.428 ± 0.004 mm. The relative error of the diameter of experimental datasets (mean ± S.D.) was 0.154 ± 0.146%. The relative errors of the distances among spheres (UC1-UA1, UC1-UB1, and UA1-UB1) were 0.007 ± 0.006%, 0.005 ± 0.005%, and 0.011 ± 0.005%, respectively (Fig. 6). The relative errors of distance were significantly smaller than that of diameter.

2. Verification of detectability

The mean surface roughness of the scanned stone board (mean ± S.D.) was 24.85 ± 1.64 μm (Table 3). Table 4 shows the mean surface roughness and depth values of gauge blocks in three experimental datasets. The mean surface roughness
of the scanned gauge blocks (mean ± S.D.) was 10.83 ± 1.23 μm. The D900 could completely distinguish the thickness difference of 10 μm, when it scans ceramic gauge blocks on the stone board. The absolute and relative error of thickness of gauge blocks was in the range of 6.78-16.88 μm, 0.65-1.53%, respectively.

3. Clinical application

Fig. 7 shows the differences in vertical height of the Model2 (after applying the splint) from the Model1 (before applying the splint). The white surface indicates the region where the difference in vertical height between two models is less than 40 μm. The red area indicates the region of Model2 above Model1, and the blue area indicates the region of Model2 below Model1. When the palate region was used as ROI for registration, there were red areas in incisal and right molar regions on the splint. In addition, when the occlusal surface was used as ROI for registration, there were blue areas in left canine region on the splint. Maximum differences in the upward and downward direction were 341 and -140 μm, respectively.

IV. Discussion

1. Volumetric analysis

Volumetric analysis for the dental 3D scanner was also performed by the manufacturers. Previously, it was investigated the results of volumetric analysis for the Optimet Multi-Facet 3D Dental Scanner\textsuperscript{12}. They performed a volumetric accuracy test by scanning a 3-sphere metrology jig with distances between the spheres of 30 mm, 40 mm, and 50 mm (sphere diameter of 19.5 mm) and comparing the sphere center position and distance with the nominal values. They concluded that the results of 40 measurement tests, on ten different scanners showed average deviations of 7.9 μm (± 5.26 μm) from the nominal dimensions. In addition, the average deviations of distances between the spheres were 6.67 μm (30 mm distance), 7.93 μm (40 mm distance) and 9.10 μm (50 mm distance). A multi facet scan test was performed by the Dental Scanner on the metrology sphere with a nominal radius of 19.5 mm with average deviations from a sphere surface of ± 5 μm with standard deviation of diameter of 6 μm. The actual measured radius was 19.062 μm, 10 μm from nominal value.

In 2006, Vlaar and Van der Zel\textsuperscript{9} evaluated a proposed test method to be used to quantify “digitizing quality” with respect to accuracy and reproducibility of two dental surface digitization devices. DentaScope II and D200 were evaluated by means of the “Sphere Test” that involved repeated measurements of a precision ball. The standard deviations for the radius of the DentaScope II and D200 were 7.7 (± 0.8) μm and 13.9 (± 1.0) μm respectively.

In our result, the standard deviation of the variation in radial height of the FN503 and D900 were approximately 1 and 5 μm. Although the diameter of UC1 and distance among spheres’ centers were calculated from the same scanned data with the D900, the relative errors of diameter (0.154%) were significantly bigger than that of distance among three spheres (0.01%). The D900 requires powder coating during the digitizing process of an object with reflective surface to reduce reflectivity. Powder coating always increase error in digitizing process\textsuperscript{13}. In this current study, powder coating has an effect on the sphere shape and size distribution of scanned data, and however little effect on the spacing deviation. These results were similar to the previous study\textsuperscript{10}. It was revealed that the D900 can produce high accuracy 3D scanning, if powder-coating was not required.
2. Verification of thickness detectability

In recent years, various intraoral and extra-oral scanners have been developed and applied in both clinical and laboratory settings. Flügge et al.\textsuperscript{14} evaluated the precision of a digital intraoral scanning under clinical conditions (iTero; Align Technologies, San Jose, USA) and compared it with the precision of an extra-oral digitizer (D250; 3Shape A/S, Copenhagen, Denmark). In the scanning for a dentition stone model, scanning with the D250 had higher precision than the intraoral scanner with mean deviations of 10 μm, median deviations of 5 μm, and root mean square errors of 20 μm. In this current study, the specimen was scanned using the dental 3D scanner, D900 with the accuracy of 7-8 μm claimed by the manufacturer. The mean deviation of variation in vertical height of the stone board was approximately 5 μm, and the surface roughness was approximately 25 μm.

An accurate measurement of the thickness differences requires profiles of both surfaces (stone board and gauge block). There was a difference between the surface roughness of stone board (approximately 25 μm) and gauge block (approximately 10 μm) portions of the same scanned data. As mentioned above, the surface roughness of the high precision steel sphere (approximately 55 μm) was bigger due to powder coating. The difference of surface roughness was due to differences of material and surface profile of the specimen. The surface roughness and minimum detectability of thickness were at a similar level of uncertainty, when the D900 scans ceramic gauge blocks. Consequently, the surface roughness is greatly affect the thickness detectability.

A minimum detectability of thickness of our evaluation system for sleep splints was verified. From the results, it was revealed that our system can detect differences of approximately 50 μm in thickness within this study limitation. It was suggested the appropriate ROI for registration should be selected depending on analytical parameters. In this case, our system can detect the occlusal facets on the surface of splint after 14 days applying using the surface of the splint region as the ROI for registration.

V. Conclusion

In this current study, the detectability of our evaluation system for sleep splints was verified. From the results, it was revealed that our system can detect differences of approximately 50 μm in thickness within this study limitation. It was suggested the appropriate ROI for registration should be selected depending on analytical parameters. In this case, our system can detect the occlusal facets on the surface of splint after 14 days applying using the surface of the splint region as the ROI for registration.

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