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Author(s) Alternative	Shimizu, T; Tasaka, A; Wadachi, J; Yamashita, S
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A new proposal for improving the accuracy of intraoral scanning for partially edentulous residual ridge

Takahiro Shimizu, Akinori Tasaka, Juro Wadachi, Shuichiro Yamashita *

Department of Removable Partial Prosthodontics, Tokyo Dental College, Tokyo, Japan

Abstract

Purpose: This study investigated the usefulness of a newly proposed intraoral scanning method, using markers that can be used directly in the oral cavity, in order to improve the accuracy of impression taking of the residual ridge for fabrication of removable partial dentures.

Methods: An intraoral scanner was used to scan a dental model of a partially edentulous mandibular arch (Kennedy Class I). As markers, pieces of dried pasta were used. The scanning operation was performed under three conditions. In Condition 1, scanning was performed on the remaining teeth and the residual ridge without markers. In Condition 2, scanning of the remaining teeth and residual ridge was performed with markers. In Condition 3, the markers were removed from the model used in Condition 2, and the residual ridge was scanned again. The scanning data of each condition was superimposed on the control data, and the shape error was calculated and compared among the conditions.

Results: There was a significant difference in trueness of the residual ridge before and after marker application. The application of markers improved the trueness, while maintaining precision. Re-scanning after removing the marker did not affect trueness between before and after re-scanning and the re-scanned region showed shape continuity with the surrounding region.

Conclusions: The present method using markers that can be used in the oral cavity was effective in improving the accuracy of impression taking at the residual ridge.

Keywords: Intraoral scanner, Accuracy, Marker, Removable partial denture

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1. Introduction

The advent of digital dentistry in recent years has greatly changed dental treatment. Use of intraoral scanners are a typical example of such changes. In the past, impressions were taken using elastomeric impression materials, and plaster casts were made from those impressions to fabricate prostheses. However, the increasing use of intraoral scanners has allowed direct acquisition of the shape of intraoral structures in the form of non-contact digital three-dimensional (3D) data [1]. Compared with the conventional method, impressions taken using an intraoral scanner avoid the deformation that can occur during the removal of impressions from the oral cavity [2] and generation of air bubbles during plaster injection. In addition, the prosthesis fabrication process is simplified, offering high degrees of satisfaction for both patients and dentists [3]. Furthermore, this method of taking impressions has certain advantages, because the information is exchanged with the dental laboratory via digital data. These advantages include reliable data storage and high reproducibility, avoidance of damage to the plaster model, reduction of model transportation costs and transportation time [4], and safety from the perspective of infection prevention [5].

Various studies have already reported the fabrication of prostheses using intraoral scanners [6,7]. For crowns and bridges, prostheses fabricated using intraoral scanners are reportedly comparable to those fabricated using conventional methods in terms of fit [8,9]. For dental implants, superstructures of up to three units in size can reportedly be fabricated using an intraoral scanner and a scan body [10,11]. Reports on the fabrication of removable prostheses have also increased in recent years [12]. In the case of complete dentures, the use of an intraoral scanner for complete digital fabrication, from impression taking and maxillomandibular registration to denture fabrication, has been described [13]. Some reports have also described the application of intraoral scanners for producing removable partial dentures, but due to the wide variation in missing tooth patterns and the complexity of denture components, there are fewer reports for these dentures than there are for fixed prostheses and complete dentures [14]. Currently, a removable partial denture can be fabricated via computer-aided design/computer-aided manufacturing (CAD/CAM) after taking impressions using conventional methods, making a plaster model, and scanning the model using a laboratory scanner. However, if intraoral scanners could be applied to the fabrication of removable partial dentures, it would confer the above-mentioned advantages to patients and will be of great significance for prosthetic clinical practice in future.

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***Corresponding author:** Shuichiro Yamashita, Department of Removable Partial Prosthodontics, Tokyo Dental College, 2-9-18 Kandamisakicho Chiyoda-ku Tokyo, 101-0061, Japan.
E-mail address: syamashita@tdc.ac.jp

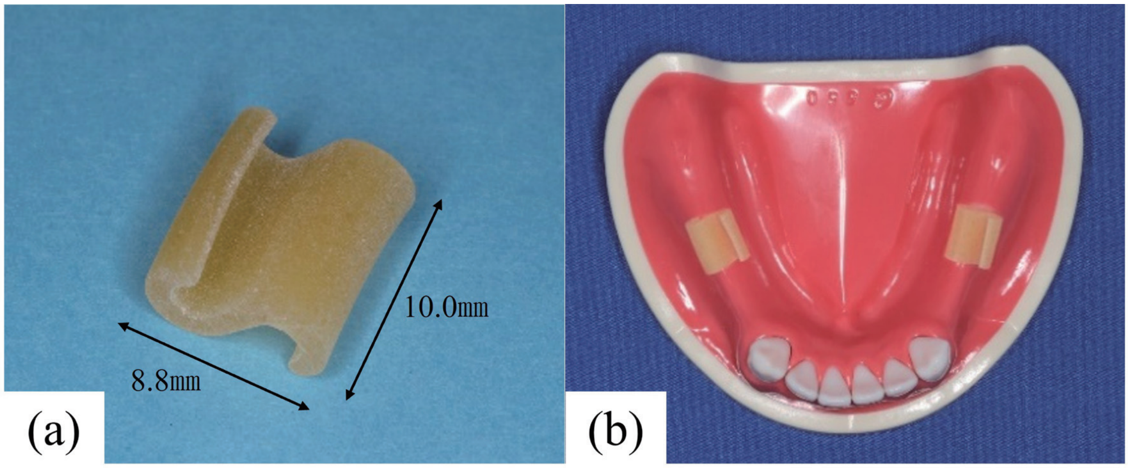

Fig. 1. Shape of the marker (a) and markers on the simulation model (b)

Various studies have examined the accuracy of intraoral scanners, and the accuracy of single-tooth scanning in the complete arch model has been reported to be comparable to that of conventional silicone impressions [15]. However, intraoral scanners may be less precise when scanning a wider area than a dental laboratory scanner [16,17], and errors reportedly increase when more than half of the dental arch is scanned [18-20]. On the other hand, soft tissue regions, such as the residual ridge of edentulous jaws, are flat as compared to the dentition [21], and their digital 3D data are easily distorted and reportedly show low trueness [22]. Intraoral scanning of a partially edentulous jaw is considered less accurate for the residual ridge than for the dentition [23]. Intraoral scanners continuously merge captured 3D images (stitching) to create the final digital 3D data, and errors are therefore more likely to occur on a flat surface with fewer irregularities, such as the residual ridge, than for the remaining teeth [24].

To reduce errors during stitching, a method to improve the accuracy of intraoral scanning by adding markers with unevenness to the residual ridge as landmarks has been trialed in a previous study [25]. However, that study examined the effect of the presence or absence of markers in improving the accuracy of scanning between distant abutment teeth, rather than focusing on improving the accuracy of the scan for the residual ridge. In addition, some studies have used markers to improve the accuracy of scanning the residual ridge [26], but such methods have not been applied clinically because the markers are firmly attached to the residual ridge of the model and are not supposed to be removed. There is a need for markers that can be attached to the oral cavity without damage and that are easily removable. Thereafter, studies can research how to improve the accuracy of scanning the residual ridge using such markers.

The purpose of the present study was to investigate the usefulness of a new scanning method using markers that can be used directly in the oral cavity in order to improve the accuracy of impression taking of the residual ridge for fabrication of removable partial dentures. The null hypothesis of the present study was that the use of markers in the oral cavity would not improve the accuracy of impression-taking for the residual ridge when using an intraoral scanner for producing partially edentulous dentition.

2. Materials and Methods

2.1. Simulation model

In the present study, a dental model of a partially edentulous mandibular arch (Kennedy Class I) with bilateral missing premolars and molars was used as a simulation model (E50-550; Nissin, Kyoto, Japan). The teeth and mucosa of the simulation model were made of resin.

2.2. Acquisition of control data

Control data were obtained using a high-precision industrial desktop scanner (ATOS Core200; GOM GmbH, Braunschweig, Germany). The simulation model was scanned, and the obtained data were converted to STL data (control data). The number of measurements was set to one. In the preliminary experiment phase, the precision of the scan data obtained by using the scanner five times was verified to be within the range of -0.04 mm to +0.04 mm.

2.3. Selection of marker and adhesive

The marker and material used for adhesion to the residual ridge were selected from those that can be applied in the oral cavity. As markers, pieces of dried pasta, 8.8 mm in width (Monsurro No. 168 (casarecce); Liguori, Italy) were chosen. This pasta shows low reflectivity and a clearly defined shape, and the characteristic S-shaped cross-section provides a broad surface area for adhesion to the residual ridge, facilitating stabilization. When this pasta was applied as a marker, pieces were cut to lengths of 10.0 mm, to be equivalent to the height of A molar. A powdered denture adhesive (Poligrip Powder Fa; GlaxoSmithKline Consumer Healthcare Japan, Tokyo, Japan) was used to attach the pasta to the residual ridge. One marker was placed at the mesiodistal center of the bilateral residual ridge on the simulation model (**Fig. 1**).

2.4. Acquisition of scanning data

An intraoral scanner (TRIOS3; 3Shape, Copenhagen, Denmark) was used to acquire the model scanning data. For both scanning and data acquisition, one dentist who was fully trained in the technique was in charge of the study. A mannequin (Simple Mannequin 3;

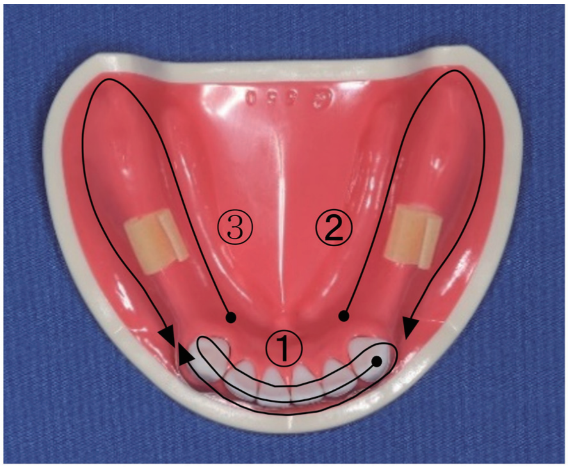

Fig. 2. Sequence of scanning with the intraoral scanner

Nissin, Kyoto, Japan) equipped with a simulation model was fixed to the headrest of a dental chair. When scanning, the head position of the mannequin was horizontal, and the dentist was in the 8 o'clock position.

The scanning path was designed to acquire data for the remaining teeth first, and then for the residual ridge. Scanning of the remaining teeth was first performed from the tip of the left canine to the tip of the right canine via the edge of the incisors, then from the right to the left on the lingual side of the anterior teeth, and finally from the left to the right on the labial side of the anterior teeth. The scanning of the residual ridge was performed first on the left side and then on the right side. Scanning was started from the lingual side of the canine, followed by the lingual part of the residual ridge, the retromolar pad, and the buccal part of the residual ridge (**Fig. 2**). In the handling of the intraoral scanner, the distance between the subject and the head of the intraoral scanner was kept as constant as possible. The scanning operation was performed under three conditions. In Condition 1, scanning was performed on the remaining teeth and the residual ridge of the model, without markers (Non-Mk data). In Condition 2, scanning of the remaining teeth and residual ridge was performed on the model, with markers (Set-Mk data). In Condition 3, the marker and adhesive used in Condition 2 were removed from the model, and the area from the tip of the canine to the residual ridge was then scanned. In Condition 3, the Set-Mk data obtained in Condition 2 were modified by re-scanning data after deleting the marker region using the trimming tool on the software of the PC connected to the intraoral scanner (Mod-Mk data) (**Fig. 3**). At that time, in the Set-Mk data, data were locked in advance using a lock tool, so that, other than in the marker region, the data could not be overwritten. Each of those three conditions was measured 10 times. In addition, the total number of images of scanning data for Conditions 1 and 2 was kept below 3000 shots to ensure adequate processing speed of the intraoral scanner [23].

2.5. Comparison of shape error and evaluation items

3D image analysis software (GOM Inspect Professional; GOM GmbH) was used to superimpose the Non-Mk, Set-Mk, and Mod-Mk data on the control data, after which shape error was calculated. The measurement points in the control data were projected onto the intraoral scanning data using the normal vectors obtained from each polygon in the control data. The "shape error" represents the true distance between the two measurement points on the control data and the intraoral scanning data. Superimposition was performed using a best-fit algorithm with the remaining teeth as the reference.

In this study, accuracy refers to trueness and precision, in accordance with the ISO standard (ISO 5725-1) [27]. Trueness is the difference between the measured value and the actual value, and precision is the degree of coincidence between each measured value over multiple measurements.

Shape error was compared for each of the four items below.

2.5.1. Comparison between Non-Mk data and Set-Mk data

In this item, the scanning accuracy in two regions of the residual ridge, anterior and posterior to the marker (anterior-to-marker region, posterior-to-marker region), were verified to confirm marker validity. Five measurement points were arbitrarily set in each of the two regions, and the average of the shape error of the five points was calculated as the representative value. Based on these representative values, the trueness and precision in two regions on each side were compared between Non-Mk data and Set-Mk data. Since the marker region of Set-Mk data showed a protruding shape, statistical comparison was omitted (**Fig. 4-1**).

2.5.2. Comparison between Set-Mk data and Mod-Mk data

In this item, Set-Mk data and Mod-Mk data were compared. We confirmed that shape data other than those of the marker region had not been overwritten by the locked processing. Five measurement points were arbitrarily set in the region on the residual ridge in the anterior part to the marker as verification region, and the average shape error of the five points was calculated as the representative value. Based on these representative values, the Set-Mk data and Mod-Mk data were compared for trueness for the left and right sides (**Fig. 4-2**).

2.5.3. Comparison between marker region and locked scanning region of Mod-Mk data

For this item, the marker region, where data were modified by re-scanning, was compared with the surrounding locked scanning region, and shape continuity of the two datasets were confirmed. Four measurement points were set up in the marker region (mesial, distal, buccal, and lingual) and four points were set up in the surrounding locked scanning region. The average shape error of each of the four points was calculated as the representative value of both. Based on these representative values, a comparison between the marker region and the locked scanning region was performed with regard to the trueness for the left and right sides, respectively (**Fig. 4-3**).

2.5.4. Comparison between Non-Mk data and Mod-Mk data

In this item, the scanning accuracy of the entire residual ridge was compared before and after the marker was applied. The residual ridge was analyzed separately for the crest (residual ridge crest) and other parts of the residual ridge (residual ridge areas). In the present study, the plane obtained by connecting the center of the left and right retromolar pads and the incisal points was used as the reference plane. The "residual ridge crest" was defined as a line drawn

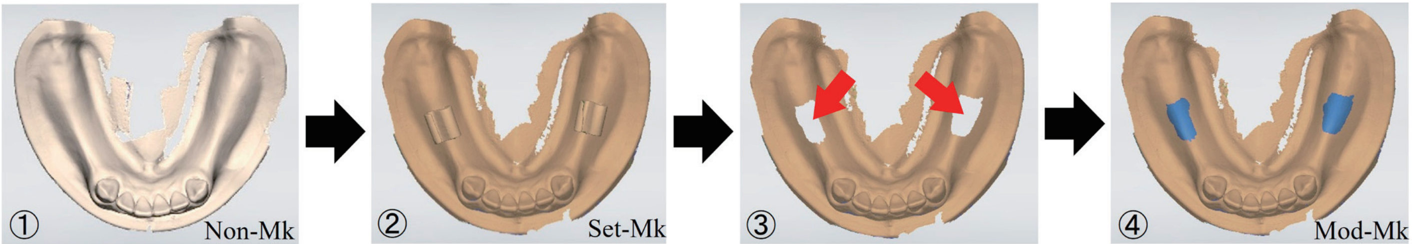

Fig. 3. Flowchart for data acquisition. 1: Non-Mk: Scanning of the simulation model without markers. 2: Set-Mk: Scanning of the simulation model with markers. 3: Red arrows indicate markers trimmed from the Set-Mk data. 4: Mod-Mk: Re-scanning of the trimmed area. Color of the original image is adjusted to distinguish between Non-Mk, Set-Mk, and Mod-Mk data.

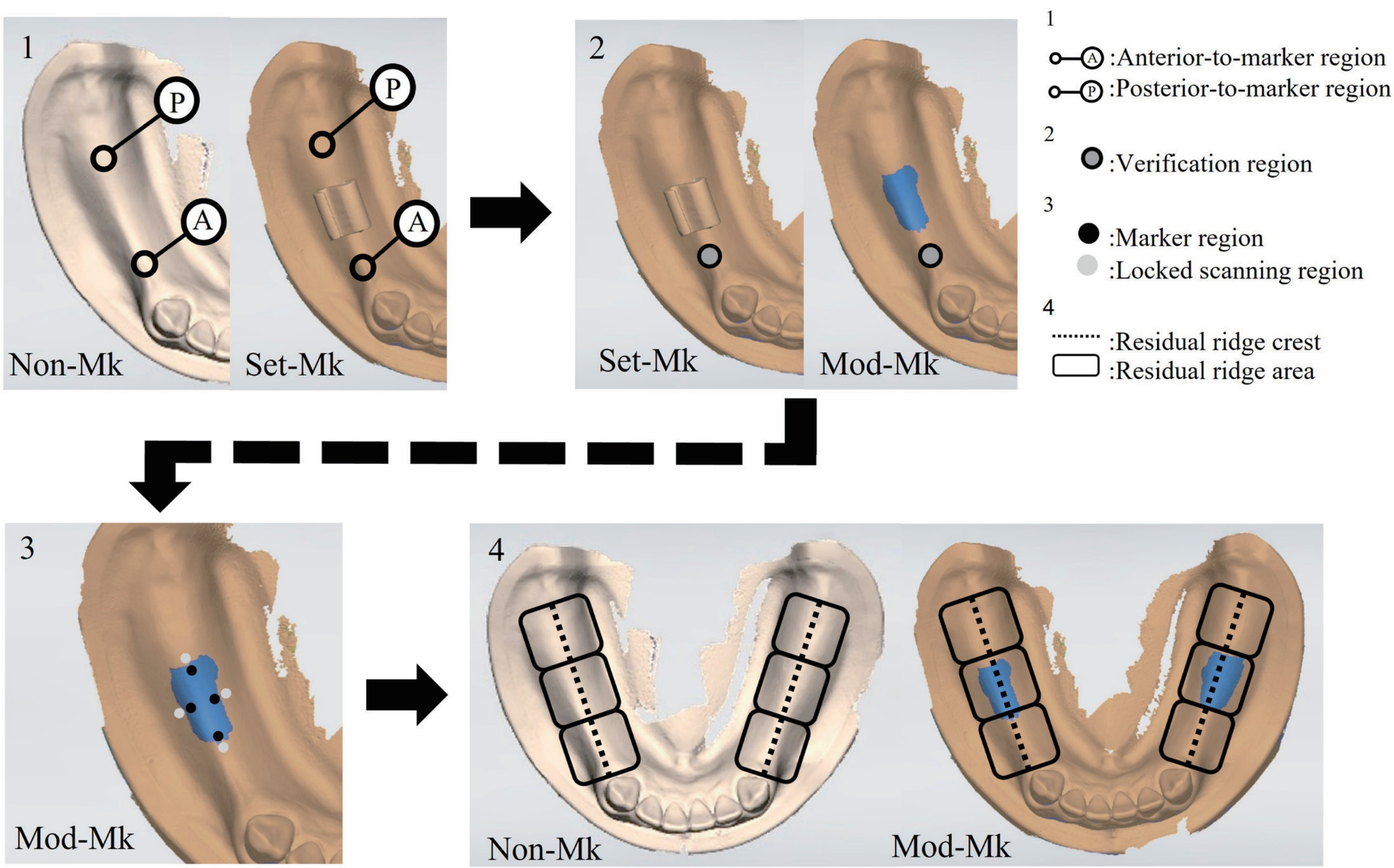

Fig. 4. Flowchart of data acquisition. 1: Comparison between Non-Mk and Set-Mk (Anterior-to-marker region, Posterior-to-marker region). 2: Comparison between Set-Mk and Mod-Mk (Verification region). 3: Comparison between Marker region and Locked scanning region in Mod-Mk data (Marker region, Locked scanning region). 4: Comparison between Non-Mk and Mod-Mk data (Residual ridge crest, Residual ridge area).

from the center of the retromolar pad to the center of the marginal gingiva of the canine centrum and projected onto the residual ridge in a viewpoint vertical to this plane. For the residual ridge crest, 39 measurement points were set at 1-mm intervals, and each of the 13 points was classified into the mesial, central, and distal regions. The average shape error of the 13 points was calculated as the representative value of the region. Residual ridge areas were also classified into mesial, central, and distal regions. Each region had 200 measurement points, at 1-mm intervals, and the average shape error of each of the 200 measurement points was calculated as the representative value of the region. The 3D image analysis software used has an "Equidistant Point" function, which was used to establish measurement points on the digital surface data. Based on these representative values, a comparison between Non-Mk data and Mod-Mk data was performed with regard to the trueness and precision for the left and right sides.

Table 1. Accuracy of Non-Mk and Set-Mk

			Non-Mk			Set-Mk			*P-value*
			Median	Q_{25}	Q_{75}	Median	Q_{25}	Q_{75}	
Tureness	Left	Anterior-to-marker region	-0.019	-0.055	0.013	0.003	-0.030	0.017	0.285
		Posterior-to-marker region	-0.332	-0.374	-0.249	-0.093	-0.160	-0.049	0.005*
	Right	Anterior-to-marker region	-0.032	-0.044	-0.022	0.008	-0.007	0.015	0.022*
		Posterior-to-marker region	-0.443	-0.516	-0.434	-0.224	-0.259	-0.188	0.007*
Precision	Left	Anterior-to-marker region	0.055	0.034	0.090	0.044	0.019	0.061	0.033*
		Posterior-to-marker region	0.091	0.047	0.125	0.123	0.054	0.173	0.089
	Right	Anterior-to-marker region	0.045	0.015	0.068	0.024	0.013	0.037	0.008*
		Posterior-to-marker region	0.067	0.032	0.120	0.060	0.041	0.112	0.879

Q_{25}: first quartile, Q_{75}: third quartile
Wilcoxon rank sum test, $*P<0.05$

Table 2. Tureness of Set-Mk and Mod-Mk in the verification region

	Set-Mk			Mod-Mk			*P-value*
	Median	Q_{25}	Q_{75}	Median	Q_{25}	Q_{75}	
Left	0.008	-0.007	0.015	0.006	-0.008	0.013	0.799
Right	0.005	-0.030	0.016	0.003	-0.030	0.017	0.799

Q_{25}: first quartile, Q_{75}: third quartile
Wilcoxon rank sum test

Table 3. Tureness of Locked scan area and Marker region in Mod-Mk

	Mod-Mk						*P-value*
	Marker region			Locked scan region			
	Median	Q_{25}	Q_{75}	Median	Q_{25}	Q_{75}	
Left	-0.007	-0.040	0.003	-0.001	-0.041	0.004	0.799
Right	-0.074	-0.095	-0.063	-0.068	-0.081	-0.054	0.799

Q_{25}: first quartile, Q_{75}: third quartile
Wilcoxon rank sum test

2.6. *Statistical analysis*

As mentioned above, trueness and precision were used to describe two components of accuracy [27]. In the present study, trueness was defined as the median of representative values obtained for each verification region (n = 10), and precision was defined as the median of the deviation between 45 combinations of 2 out of 10 representative values.

The Shapiro-Wilk test was used to confirm normal data distributions. Bartlett's test was used to evaluate the homogeneity of variance for all tests. The Wilcoxon signed-rank sum test was used to compare shape error in terms of the four items. All analyses were performed using SPSS statistical software (version 21; IBM, New York, USA), with the significance level set at 0.05.

3. Results

3.1. *Comparison between Non-Mk data and Set-Mk data*

The median trueness of the four regions on the left and right sides ranged from -0.443 to -0.019 mm for Non-Mk data and from -0.224 to 0.008 mm for Set-Mk data. The Set-Mk data showed better trueness than did Non-Mk data, with a significant difference between these data sets in all regions except the left anterior-to-marker region (**Table 1**).

The median precision of the four regions on the left and right sides ranged from 0.045 to 0.091 mm for the Non-Mk data and from 0.024 to 0.123 mm for the Set-Mk data. The Set-Mk data showed better precision than did the Non-Mk data in bilateral anterior-to-marker regions, with a significant difference between them.

3.2. *Comparison between Set-Mk data and Mod-Mk data*

The median trueness of the verification region was 0.008 mm for Set-Mk data and 0.006 mm for Mod-Mk data on the left side, and 0.005 mm for Set-Mk data and 0.003 mm for Mod-Mk data on the right side (**Table 2**). On both the left and right sides, the Set-Mk data and Mod-Mk data showed the same degree of trueness, with no significant difference between them.

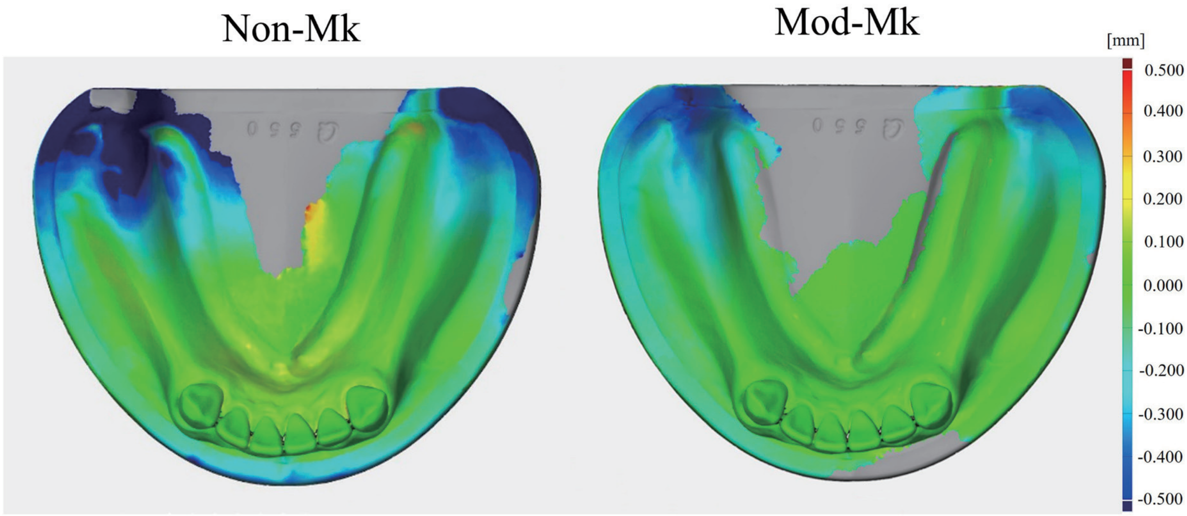

Fig. 5. Color map indicating the trueness of intraoral scanning. Yellow to red indicates a positive shape error (scanning data displaced toward the outside relative to control data), blue indicates a negative shape error (scanning data displaced toward the inside relative to control data), and green indicates a high degree of trueness.

3.3. Comparison between marker region and locked scanning region of Mod-Mk data

The median trueness of the verification region was -0.007 mm for the marker region and -0.001 mm for the locked scanning region on the left side, and -0.074 mm for the marker region and -0.068 mm for the locked scanning region on the right side. On both the left and right sides, the marker region and locked scanning region showed the same degree of trueness, with no significant difference between them. Shape continuity between the marker region where the data were modified by re-scanning, and the surrounding locked scanning region was found.

3.4. Comparison between Non-Mk data and Mod-Mk data

Figure 5 shows a typical color chart for Non-Mk and Mod-Mk data. In the color chart, yellow to red indicates a positive shape error (scanning data displaced toward the outside relative to control data), blue indicates a negative shape error (scanning data displaced toward the inside relative to control data), and green indicates a high degree of trueness. Compared to Non-Mk data, Mod-Mk data showed more area in green overall and less area in blue in the distal region of the residual ridge. This indicates that Mod-Mk data have a larger area of high trueness than Non-Mk data, particularly in the distal region of the residual ridge.

Median trueness of the six regions on the left and right sides of the residual ridge crest ranged from -0.447 to 0.004 mm for Non-Mk data and from -0.242 to 0.033 mm for Mod-Mk data (**Table 4**). With the exception of the left mesial region, the Mod-Mk data showed better trueness than did the Non-Mk data, and there was a significant difference between these data sets in all regions. Median precision of the same region ranged from 0.014 to 0.080 mm for Non-Mk data and from 0.019 to 0.091 mm for Mod-Mk data. A significant difference between the two datasets was seen only in the central region of the right side.

Median trueness of the six regions on the left and right sides of the residual ridge areas ranged from -0.308 to 0.004 mm for Non-Mk data and from -0.153 to 0.028 mm for Mod-Mk data. With the exception of the left mesial region, Mod-Mk data showed better trueness than Non-Mk data, with a significant difference between these data in all regions. Median precision of the same region ranged from 0.019 to 0.052 mm for Non-Mk data and from 0.014 to 0.061 mm for Mod-Mk data. A significant difference between the two datasets was seen only in the mesial region of the right side.

4. Discussion

4.1. Scanning with markers

In the present study, both the markers and adhesive used were chosen for their biosafety and amenability to intraoral use for clinical applications. The marker, which consisted of dried pasta pieces, was mainly comprised of carbohydrates, while the adhesive was mainly composed of sodium, both of which are non-injurious to the oral cavity and can be applied clinically. In addition, the markers had low reflectivity, facilitating shape recognition by the intraoral scanner camera and subsequent scanning. The powdered denture adhesive ensured secure fixation of the markers even under highly humid and wet conditions and was easy to remove after adhesion. These results suggested that the marker and adhesive used in the present study are appropriate materials for use in the oral cavity.

In the comparison between Non-Mk and Set-Mk data, the use of markers improved trueness in the posterior region, where trueness was not optimal for Non-Mk data. No difference was seen in precision, suggesting that marker-mediated scanning improved the accuracy of scanning [25]. Diker *et al.* reported the possibility of a difference in scanning error between the start and end of scanning, and that the accuracy of scanning is lower in the area far from the start of scanning [28]. The wider the scanning area, the more stitching errors occur and the less accurate is the scan. In the posterior region of the residual ridge, which is expected to have many stitching errors,

Table 4. Accuracy of Non-Mk and Mod-Mk

Residual ridge crest			Non-Mk			Mod-Mk			*P-value*
			Median	Q_{25}	Q_{75}	Median	Q_{25}	Q_{75}	
Tureness	Left	Mesial	0.004	-0.020	0.023	0.033	0.012	0.041	0.022*
		Center	-0.074	-0.131	-0.052	0.002	-0.033	0.012	0.017*
		Distal	-0.292	-0.349	-0.231	-0.099	-0.168	-0.075	0.007*
	Right	Mesial	-0.031	-0.032	-0.021	0.004	-0.007	0.012	0.007*
		Center	-0.185	-0.194	-0.181	-0.087	-0.124	-0.077	0.005*
		Distal	-0.447	-0.505	-0.438	-0.242	-0.253	-0.195	0.005*
Precision	Left	Mesial	0.031	0.018	0.049	0.028	0.013	0.042	0.474
		Center	0.064	0.031	0.084	0.050	0.031	0.089	0.977
		Distal	0.080	0.046	0.115	0.091	0.038	0.143	0.185
	Right	Mesial	0.015	0.010	0.029	0.019	0.009	0.027	0.569
		Center	0.014	0.005	0.030	0.034	0.016	0.056	0.020*
		Distal	0.069	0.026	0.095	0.052	0.017	0.078	0.183
Residual ridge area			Non-Mk			Mod-Mk			*P-value*
			Median	Q_{25}	Q_{75}	Median	Q_{25}	Q_{75}	
Tureness	Left	Mesial	0.004	-0.015	0.022	0.028	0.012	0.039	0.028*
		Center	-0.056	-0.079	-0.028	0.014	-0.013	0.020	0.009*
		Distal	-0.177	-0.216	-0.144	-0.048	-0.090	-0.028	0.005*
	Right	Mesial	-0.033	-0.043	-0.026	0.004	0.001	0.008	0.008*
		Center	-0.123	-0.142	-0.119	-0.048	-0.060	-0.041	0.005*
		Distal	-0.308	-0.330	-0.288	-0.153	-0.158	-0.128	0.005*
Precision	Left	Mesial	0.024	0.014	0.039	0.019	0.010	0.031	0.132
		Center	0.035	0.019	0.055	0.035	0.022	0.056	0.576
		Distal	0.052	0.028	0.074	0.061	0.029	0.090	0.081
	Right	Mesial	0.019	0.013	0.033	0.014	0.006	0.020	0.000*
		Center	0.027	0.014	0.034	0.022	0.012	0.035	0.388
		Distal	0.043	0.021	0.067	0.035	0.008	0.045	0.257

Q_{25}: first quartile, Q_{75}: third quartile
Wilcoxon rank sum test, *$P<0.05$

Set-Mk data showed the same precision and improved trueness as did the Non-Mk data, suggesting that stitching errors were reduced by the application of markers. In the present study, the height of the marker was set at 5 mm. Preliminary experiments have confirmed that the marker is clinically applicable in the actual oral cavity, as there was enough space for scanning at a 40-mm opening even when the marker was attached.

Changing the size or increasing the number of markers may further improve the accuracy of intraoral scanning, but excessive marker size or number of markers may make intraoral scanning difficult and reduce the accuracy of scanning. If the area occupied by the markers is too large for the area of the crest to be scanned, the accuracy may also be reduced.

Depending on the position of the marker, the distance between the most posterior tooth and the marker may be further, resulting in early stitching errors and reduced scanning accuracy. Further study of these issues is needed.

4.2. Effect on trueness of re-scanning the residual ridge under the marker

In the Set-Mk data, shape data for the residual ridge under the marker were not available. Therefore, after scanning with the marker present, the marker was removed from the model and data for the marker area were partially deleted on the PC. Data for the residual ridge were then obtained by re-scanning the area. Reich *et al.* have already reported that re-scanning an object with the same shape after deleting the data does not affect the accuracy of the re-scanned region [29]. In the present study, since the shape of targets differed between before and after re-scanning, we verified whether re-scanning had any effect on trueness. No significant difference was found between Set-Mk data and Mod-Mk data in terms of the trueness of the anterior part of the marker, which was the verification region, indicating that the locked processing functioned effectively. In Mod-Mk data, no significant difference was evident between the marker region and the surrounding locked scanning region, indicating shape continuity between the marker region that had been modified by re-scanning the surrounding area.

4.3. Verification of the effectiveness of the present method

The present results showed a significant difference in trueness of the residual ridge between Non-Mk and Mod-Mk data. Trueness of the Mod-Mk data tended to improve in both the left and right sides, except for the left mesial region, and the application of markers improved the trueness of Mod-Mk data by 46-97% in the residual ridge crest and by 50-87% in residual ridge areas. On the other hand, no difference in precision was seen according to the presence or absence of markers, except in some regions. This suggests that the present method using markers can improve trueness while maintaining precision. The null hypothesis of the present study, that "the use of markers in the oral cavity would not improve the accuracy of impression-taking for the residual ridge, when using an intraoral scanner for partially edentulous dentition," was therefore rejected.

As for the direction of shape error, Non-Mk data showed negative shape error in the distal and central regions of the residual ridge. With conversion from Non-Mk data to Mod-Mk data, although shape error remained negative, shape error became weaker or even slightly positive. On the other hand, in the mesial region, shape error was small even with Non-Mk data without markers, because this region was close to the remaining teeth. No clear trend was observed by converting to Mod-Mk data as described above.

The time required for Mod-Mk data acquisition was about 5-6 minutes. In vitro experiments reported that the conventional method, using elastic impression material, required 10 minutes from the start of impression to removal [30]. The present method is expected to reduce the impression-taking time by about 40-50%.

4.4. Limitations of the present study and future prospects

When fabricating an extension-base removable partial denture, there is a need to compensate for differences in the amount of pressure displacement between the remaining teeth and residual ridge. The pressure impression method using silicone material, which has been recommended in the past, is a method for taking impressions of the residual ridge under functional pressure to protect the remaining teeth by compensating for differences in the amount of displacement between the remaining teeth and residual ridge.

Two major problems are encountered when scanning data of the residual ridge is assumed to be used for the fabrication of removable partial dentures. The first problem is that impressions taken with intraoral scanners are non-contact and cannot compensate for differences in pressure displacement between the remaining teeth and residual ridge, because application of pressure to the residual ridge is impossible when performing intraoral scanning. To address this problem, two methods may be applicable: 1) fabrication of a working model and a partial denture framework from scanning data obtained by an intraoral scanner, and application of pressure to the residual ridge using the altered cast technique; or 2) modification of scanning data for the residual ridge on CAD by considering the amount of pressure displacement. A second problem is the inability to obtain data on the functional morphology of movable tissues, such as the oral vestibule, lips, tongue, and cheeks. The development of a new device, and updates to the software and hardware to address these problems, are required [31].

In addition, another limitation was that the present study was conducted under in vitro conditions, and thus did not take into account the salivary wetness of the oral cavity, the degree of reflection of the remaining teeth [32-34] or mucosa of the residual ridge, or the presence of movable mucosa. The present study simulated only one case of a typical partially edentulous mandibular arch classified as Kennedy Class I, and further studies are needed to determine whether the accuracy of the present results can be achieved in cases with different ranges of missing teeth and different shapes of the residual ridge. Furthermore, only one type of intraoral scanner was used in the present study. Further validation is needed to determine whether similar results can be obtained with different intraoral scanners.

5. Conclusions

In the present study, the usefulness of a new scanning method using markers that can be applied in the oral cavity was investigated to improve the accuracy of impression-taking of the residual ridge using an intraoral scanner. We found that the application of markers to the residual ridge for clinical use appears to be effective for improving the accuracy of intraoral scanning. In terms of re-scanning after removing the marker, trueness was unaffected between before and after re-scanning, and the re-scanned region showed shape continuity with the surrounding region.

Conflicts of interest

There are no conflicts of interest to declare in regard to this study.

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