Effect of scanning pathways on trueness and precision in full-arch optical impression

Shota Kuroda (kurodasyouta@tdc.ac.jp)
Tokyo Dental College

Mamoru Yotsuya
Tokyo Dental College

Toru Sato
Tokyo Dental College

Ryuichi Hisanaga
Tokyo Dental College

Syuntaro Nomoto
Tokyo Dental College

Hideshi Sekine
Tokyo Dental College

Research Article

Keywords: Optical impression, Intra oral scan, Scanning pathway, Trueness, Precision

Posted Date: February 17th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-2559757/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License
Abstract

**Background:** In this study, we investigate the effect of differences in scanning pathway during optical impression on the trueness and precision of full-arch impressions.

**Methods:** Reference data were obtained using a lab scanner. All the optical impressions were measured across the dental arch using TRIOS® 3 in four different pathways. The reference data and optical impression data were superimposed using a best-fit method. The criteria for superimposition included the center of one starting side dental arch (partial-arch best-fit method : PB) and the center of full-arch (full-arch best fit method : FB). Data were compared between the left and right molars (starting and ending sides). The mean values (scan deviations) of trueness (n = 5) and precision (n = 10) were calculated after the difference in deviation between each group was absolutized. Visual observations using the superimposed color map images showed the variation in trueness.

**Results:** There was no signicant difference in scanning time or the amount of scan data between the four scanning pathways studied. Trueness did not differ significantly among the four pathways with respect to starting and ending sides, regardless of superimposition criteria. Precision with PB was significantly different between scanning pathways A and B, between pathways B and C for the starting sides and between scanning pathways A and B, between pathways A and D for the ending sides. In contrast, there was no significant difference between starting sides and ending sides pathways for FB. For PB, color map images showed a large error range in the direction toward the molar radius for occlusal surface and cervical regions on the ending sides.

**Conclusion:** Differences in scanning pathways did not affect trueness, regardless of superimposition criteria. Scan pathway B on the starting side and scan pathway D on the ending side were the most accurate, and the difference in scanning pathways was observed to affect the precision of PB.

**Background**

In recent years, advances in digital technology have led to the digitization of prosthetic devices in the dental industry, with a centering on CAD/CAM systems. This production process consists of four main steps. The first step is to obtain an impression of abutment tooth and dental arch, the second step is to digitize the model, the third step is to design a prosthetic device using CAD software, and the fourth step is to fabricate a prosthetic device using CAM, which is a method of indirectly digitizing information in the oral cavity [1, 2]. Optical impression technology, which uses intraoral scanners (IOS) to digitize information in the oral cavity directly, has attracted attention in recent times [3–5]. IOS can quickly build a three-dimensional model by capturing still images or videos of hard and soft tissues. The optical impression method is characterized by shortened chair time, reported to be more comfortable to the patients due to less gagging with limited vomiting reflexes and oral opening function, preventing infection and reducing the use of materials, eliminating the need for storage space owing to the digitalization of impressions, and easy communication with the technical laboratory.
Many studies on optical impression methods applied in the crown prosthesis fields focused on the compatibility of single crowns or short span bridges of approximately 4 units [6–8]. With single-tooth optical impressions, the precision reported for IOS was comparable to that of conventional methods using silicone impression materials [9]. For short span scans and implant-based prosthetic treatments, the risk of error with digitization was reported to be low [10, 11]. In recent years, there has been an increase in the reported precision of full-arch procedures requiring long-span reconstruction. Such cases are common in the clinical setting. However, a rise in measurement errors has been reported with an increase in the length of teeth measured [2, 12]. The full-arch optical impression method demonstrated the same precision in an in vitro study as that of conventional impression methods [13], although others concluded that its precision is lower than that of conventional methods [6, 14, 15].

Factors contributing to scanning data error with IOS include differences in scanning approach [16–18], IOS image type (photo or video), the presence or absence of powder [19, 20], the size of the scanner head [21], hand abrasions during scanning, and patient movement. These factors provide a scanning pathway for full-arch. Many IOS suggest the full-arch scanning pathways of various manufacturers. However, many aspects of their applicability remain unclear. As such, the effect of differences between scan pathways on the accuracy of full-arch and tooth-level measurement has not been sufficiently investigated.

In this study, we investigate the effect of differences in scanning pathway during optical impression on the trueness and precision of full-arch impressions.

**Methods**

Reference model

This study considers the teeth located in the lower jaw, and the mandibular model (D-18-500H (GUB) -MF: NISSIN, Kyoto, Japan) was used as the reference model. Reference data were acquired without scanning the reference model using a dental technical scanner (D2000: 3 Shape, Copenhagen, Denmark).

Measurement method

Intraoral scanner (IOS)

In this study, TRIOS® 3 (3 Shape, Copenhagen, Denmark) was used as the IOS with the confocal method as the scanning principle. TRIOS® 3 does not powder while scanning, per manufacturer instructions. Prior to scanning, the scanner tip was calibrated and preheated as instructed by the manufacturer.

Scan environment

The reference model assumes real clinical situations and mimics a patient placed in the dental unit (SIMPLE MANIKIN: NISSIN, Kyoto, Japan) (Fig. 1). At this time, the height of the unit was set to 50 cm from the floor so that the occlusal plane was horizontal, and the back plate was position inclined to a 30°.
Scanning pathways and time/amount of data

Optical impressions involved the operator positioned in front of the patient (8 o’clock position). The entire dental arch was measured five times each in four different scanning pathways (A, B, C, D) from the left mandible second molar (starting side) to the right mandible second molar (ending side) (Fig. 2).

Scanning pathway A was scanned in the order of occlusal surface, buccal side, and lingual side. Scanning pathway B was scanned in the order of occlusal surface, lingual side, and buccal side. Scanning pathway C was scanned in the same order as that of scanning pathway B for a single sextant until the left mandibular first molar, and a series of scans were performed for a single sextant unit for the front and right mandibular molars as well. Scanning pathway D was scanned in an S shape across all teeth in single-tooth order on the lingual side, occlusal surface, and buccal side. The time required for scanning and the number of data acquired were also recorded for each scan. The scans were performed sequentially without stopping or resuming repeatedly during the scan. All scans were performed by a dentist who was adequately experienced in scanning.

Image analysis and data evaluation

All the measurement data are input into CAD software (Dental System: 3 Shape, Copenhagen, Denmark) and converted to STL data. Subsequently, data were imported using 3D measurement software (Dmat3DE: DIGITAL PROCESS LTD., Kanagawa, Japan). Then, after trimming excess soft tissue such as gums, data were superimposed using a best-fit method (Vote method). The criteria for superimposition were set for two patterns, either centering on the starting side of a dental arch (partial-arch best-fit method (PB)) or the full-arch (full-arch best-fit method (FB)). The trueness of the starting side and ending side molars was determined by superimposing the scan data of each scanning pathway with the reference scan data (n = 5).

Precision was superimposed between the scan data for each scanning pathway (n = 10). The precision was compared by combining two of the five measured data. Therefore, the data per scan pathway was 10.

After absolutization of the trueness and precision for deviation within each group, the mean values were calculated (scan deviation). The scan deviation was determined by calculating the root mean square (RMS) of the deviation amount at each measurement point.

In addition, the color map image after superimposition for trueness was used as a visual observation of the deviation trend to determine the ± deviation between the two data sets. The deviation ranges of the starting side and ending side molars were visually observed, and the area of greatest deviation in the
color map by single tooth units was selected as the representative value. Deviations include positive and negative values, with positive values shown as warm-colored and reference data shown as convex (enlarged). In contrast, the negative values are cold-colored and reference data are shown as pits (minimized). The minimum range of deviation (green area) was set to ± 50 µm and the maximum deviation value was set to ± 500 µm.

**Statistical analysis**

Statistical analyses were performed using the Mann–Whitney U test and Kruskal–Wallis test to examine the effect of each scanning pathway on the trueness and precision for FB and PB, with a significance level of 5%.

**Results**

Scanning time and amount of scan data

The results are shown in Table 1. The mean scanning time was 78.4 ± 4.5 s for scanning pathway A, 87.6 ± 4.3 s for scanning pathway B, 76.2 ± 1.0 s for scanning pathway C, and 83.2 ± 7.1 s for scanning pathway D.

<table>
<thead>
<tr>
<th></th>
<th>Pathway A</th>
<th>Pathway B</th>
<th>Pathway C</th>
<th>Pathway D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average scanning time (Sec)</td>
<td>78.4±4.5</td>
<td>87.6±4.3</td>
<td>76.2±1.0</td>
<td>83.2±7.1</td>
</tr>
<tr>
<td>Average scanning data (Slices)</td>
<td>1,065.2±22.6</td>
<td>1,168.2±58.8</td>
<td>1,055.2±44.0</td>
<td>1,108.8±51.3</td>
</tr>
</tbody>
</table>

The average scanning time was less than 90 seconds and the average scanning data amount (slices) was about 1100 slices in all scan pathways, and there was no significant difference between the scan pathways.

The mean amount of scan data was 1,065.2 ± 22.6 for scanning pathway A, 1,168.2 ± 58.8 for scanning pathway B, 1,055.0 ± 44.0 for scanning pathway C, and 1,108.8 ± 51.3 for scanning pathway D.

Scan deviation due to different scanning pathways

The results of scanning deviations for each group are shown by the box plots in Figs. 3–6. The box plot contains 25 percentile and 75 percentile values of scan deviation (median line, median), and the vertical
Trueness

For PB, the median starting side trueness was 98.0 µm (interquartile range = 26.0) for scanning pathway A, 89.0 µm (interquartile range = 24.5) for scanning pathway B, 106.0 µm (interquartile range = 9.5) for scanning pathway C, and 105.0 µm (interquartile range = 14.0) for scanning pathway D. The median ending side trueness was 190.0 µm (interquartile range = 46.0) for scanning pathway A, 196.0 µm (interquartile range = 52.0) for scanning pathway B, 222.0 µm (interquartile range = 53.0) for scanning pathway C, and 183.0 µm (interquartile range = 57.0) for scanning pathway D. The median starting side trueness was approximately 100 µm (interquartile range = 9.5–26.0) across all the scanning pathways. In contrast, the median ending side trueness was approximately 200 µm (interquartile range = 46.0–57.0) across all the scanning pathways, and the deviation was greater than that of starting-side trueness. In addition, there was no significant difference in trueness between the starting and ending sides for any scanning pathways (Fig. 3).

For FB, the median starting side trueness was 105.0 µm (interquartile range = 27.0) for scanning pathway A, 99.0 µm (interquartile range = 32.5) for scanning pathway B, 110.0 µm (interquartile range = 8.0) for scanning pathway C, and 112.0 µm (interquartile range = 14.0) for scanning pathway D. The median ending side trueness was 95.0 µm (interquartile range = 44.5) for scanning pathway A, 114.0 µm (interquartile range = 44.5) for scanning pathway B, 82.0 µm (interquartile range = 20.0) for scanning pathway C, and 117.0 µm (interquartile range = 37.0) for scanning pathway D. The median starting side trueness was approximately 100 µm (interquartile range = 8.0–32.5) across all the scanning pathways. In contrast, the median ending side trueness was approximately 100 µm (interquartile range = 20.0–44.5) across all the scan pathways, and although the interquartile range was large, it was similar in size to starting side trueness. In addition, there was no significant difference in trueness between the starting and ending sides for any scanning pathway (Fig. 4).

Precision

For PB, the starting side precision had the median values of 38.5 µm (interquartile range = 7.0) for scanning pathway A, 28.0 µm (interquartile range = 6.0) for scanning pathway B, 44.5 µm (interquartile range = 22.0) for scanning pathway C, and 34.5 µm (interquartile range = 15.0) for scanning pathway D. Significant differences were observed between the scanning pathways A and B, between pathways B and C. For PB, the ending side precision had the median values of 134.0 µm (interquartile range = 79.0) for scanning pathway A, 83.5 µm (interquartile range = 51.0) for scanning pathway B, 104.5 µm (interquartile range = 36.0) for scanning pathway C, and 89.0 µm (interquartile range = 28.0) for scanning pathway D. The median starting side precision was approximately 35 µm (interquartile range = 6.0–22.0) across all the scanning pathways. However, the median ending side precision was approximately 103 µm
(interquartile range = 28.0–79.0) across all the scanning pathways. Significant differences were observed between the scanning pathways A and B, between pathways A and D (Fig. 5).

For FB, the starting side precision had the median values of 52.0 µm (interquartile range = 29.0) for scanning pathway A, 41.0 µm (interquartile range = 19.0) for scanning pathway B, 51.0 µm (interquartile range = 29.0) for scanning pathway C, and 41.5 µm (interquartile range = 12.0) for scanning pathway D. The ending side precision had the median values of 54.0 µm (interquartile range = 20.0) for scanning pathway A, 52.5 µm (interquartile range = 34.0) for scanning pathway B, 48.5 µm (interquartile range = 14.0) for scanning pathway C, and 51.5 µm (interquartile range = 14.0) for scanning pathway D. The median starting side precision was approximately 46 µm (interquartile range = 12.0–29.0) across all the scanning pathways. In contrast, the median ending side precision was approximately 50 µm (interquartile range = 14.0–34.0) across all the scanning pathways, and although the interquartile range was large, it was similar in size to starting side precision. In contrast to PB, there was no significant difference between the starting and ending sides for any scanning pathway (Fig. 6).

Color map images and deviation distribution

Figures 7 and 8 show the color maps generated by superimposing trueness values. Tables 2 to 5 show the largest ranges of color map trueness values by single-tooth units as representative values.

**Table 2. Deviation distribution by tooth for PB starting side (trueness).**

<table>
<thead>
<tr>
<th>Type of tooth</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>450+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>350–450</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>250–350</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150–250</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50–150</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>±50</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>±400</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For all the color map images, the maximum deviation area was observed for each tooth.

**Table 3. Deviation distribution by tooth for PB ending side (trueness).**
For all the color map images, the maximum deviation area was observed for each tooth.

Table 4. Deviation distribution by tooth for FB starting side (trueness).

| Type of tooth | 47 | 46 | 45 | 44 | 47 | 46 | 45 | 44 | 47 | 46 | 45 | 44 | 47 | 46 | 45 | 44 | 47 | 46 | 45 | 44 | 47 | 46 | 45 | 44 | 47 | 46 | 45 | 44 |
|---------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 100-300       | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| 250-300       | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| 300-350       | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| 350-400       | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| 400-450       | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |

For all the color map images, the maximum deviation area was observed for each tooth.

Table 5. Deviation distribution by tooth for FB ending side (trueness).

| Type of tooth | 47 | 46 | 45 | 44 | 47 | 46 | 45 | 44 | 47 | 46 | 45 | 44 | 47 | 46 | 45 | 44 | 47 | 46 | 45 | 44 | 47 | 46 | 45 | 44 | 47 | 46 | 45 | 44 |
|---------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 100-300       | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| 250-300       | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| 300-350       | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| 350-400       | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| 400-450       | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |

For all the color map images, the maximum deviation area was observed for each tooth.
For all the color map images, the maximum deviation area was observed for each tooth.

With PB, the starting side trueness mostly showed a range of ± 50 µm among all the scanning pathways (Table 2). For the ending side, the deviation mainly ranged from −150 to −450 µm on the occlusal surface and buccal cervical regions (Table 3). The negative trend was particularly strong toward the molar distal region (Fig. 7).

With FB, the starting-side trueness mostly showed a range of +50 to +150 µm among all the scanning pathways (Table 4). The ending side trueness showed a scattered range of ±50 to ±250 µm among all the scanning pathways (Fig. 8) (Table 5).

**Discussion**

**Setting scanning pathway**

In this study, we investigated the effect of scanning pathway on the accuracy of full-arch optical impressions assuming long span reconstruction. Past studies on optical impressions are based on metal models made of Co-Cr alloys and Ti to minimize the deformation of the focal dental models [1, 13, 22]. However, metallic reference models produce strong reflection during scanning on the surface of models, which can result in a loss of data and scan failure. Thus, an epoxy resin model with minimal reflection and high dimensional stability was used as the reference model [23]. Optical impressions were also performed with reference models attached to mannequins placed on the dental unit to mimic standard patient conditions [24]. To suppress the reflection of the model surface as much as possible during the scan, non-shadow lamps were avoided in favor of natural lighting according to the manufacturer's instructions.

In this study, four pathways were chosen to scan optical impressions. All the pathways were scanned from the left mandibular second molar occlusal surface [25] to facilitate stitching during scanning. Scanning pathways A and B are common only to the occlusal surface at first, but we also scanned the opposing molar regions. When using the optical impression for prosthetics, it was recommended that the scanning range not exceed a single sextant [2, 26, 27]. Accordingly, scanning pathway C was scanned a single sextant unit. Finally, scanning pathway D was scanned in single-tooth units, either in an S-shape or zig-zag pattern [22, 23], primarily to allow for effective scanning of the anterior teeth. For both scanning pathways C and D, we did not perform a single broad scan. Rather, we scanned a single sextant or tooth-by-tooth. Thus, the four scanning pathway can be separated into two large scan ranges run at once. Therefore, this study allows us to consider how the difference in scanning range (distance) affects the trueness and precision of three-dimensional data.

**Best-fit method**
Post-scan three-dimensional data were superimposed with reference data or acquired data using three-dimensional measurement software after conversion to STL data. The D2000® dental laboratory scanner used to scan the reference model adopted a multi-line scanning method using blue LED light with a scanning precision of ±5 µm. Dental laboratory scanners can be measured from a wide range of angles with high-performance cameras while shielding natural light, unlike with IOS. Thus, this technology allowed us to obtain high-precision data, and it has been used in several studies to obtain reference data [12].

Several studies reported the accuracy of optical impression superimposition, citing three-dimensional data obtained based on best-fit methods [2, 4, 15, 22, 27–30]. Characteristics of this method include visual representation of the entire three-dimensional model depression, making it possible to assess displacement by color mapping [1, 10, 14, 31].

However, this method is not suitable for the evaluation of error at particular points (e.g., distances between the centers of multiple ball abutments). Therefore, the best-fit algorithm is not used in implantology research. Rather, such studies are evaluated by finding the central coordinates of two ball abutments and calculating the distance between them [12, 28]. A disadvantage of this method is that variation within the entire model cannot be evaluated stereoscopically, given that error is evaluated as the distance between the central coordinates at arbitrary points. This method may also lack reproducibility and incorporate measurement bias [28, 30]. In this study, data superimpositions were performed using the aforementioned best-fit algorithm that allows assessment of the dentition for studying optical impression methods in the fixed prosthodontics region.

Selecting best-fit method criteria

Most studies using the best-fit algorithm method overlap the full-arch using the least squares method [14, 32]. When using the least squares method for superimposition, software adjusts the parameters so that there are no significant deviations or variations in the data as a whole. Therefore, this method is suitable for assessing whether the target and reference objects are mostly similar in shape. The Vote method was used in this study. The Vote method superimposes polygons throughout the data at points where there is minimal deviation. As points of high error are not used for superimposition, small regions represent small error and large regions represent large deviation. Therefore, this method is suitable for measuring the deviation between data sets. The algorithm most likely attempted to register the surfaces in such a way that the overall mean deviation between the surfaces was minimized, which may conceal an increase in deviation between the surfaces and make interpretation of deviation difficult. A best-fit algorithm based only on areas where the scan was started may have shown an increase in deviation [16]. In this study, a starting-side scan from the left molar region and a full-arch scan were obtained to create two reference superimpositions.

Effects on scanning time and data count
The scanning time was shorter than that of conventional methods using silicone impression materials in all the scanning pathways [24]. In addition, the amount of scanned data does not exceed the upper limit (2000 slices) for optimal post-scan data transmission, and the scan path settings used in this study were considered appropriate for standard clinical application.

Effects on scanning pathway trueness

IOS accuracy is assessed primarily by two measures: “trueness” and “precision” (ISO 5725-1) [33]. Trueness is defined as the deviation from reference data values [13, 33–35].

There was no significant difference between the starting sides and ending sides for both PB and FB with any scanning pathways. Depending on the digital system used, there have been reports [29] that show no effect on trueness with different scanning pathways. Another report [23] suggests that the accuracies of TRIOS®, Omnicam®, and 3M™ True Definition Scanner are unaffected by the differences in scanning method when recording impressions over long spans. These results are consistent with the findings of this study. Therefore, in this study, the degree of authenticity was not affected by the differences in scanning pathways. Many previous studies used the second-generation TRIOS® Pod or TRIOS® Color [2–6, 9, 12]. In this study, the TRIOS® 3 is the third generation. There are differences in scan speed and system version. However, the TRIOS® 3 has common systems such as scanning principle and powderless.

PB and FB trueness showed similar values for the starting side, but for PB, the ending side trueness was lower than that for FB.

Effects on scanning pathway precision

Precision may refer to reproducibility and is defined as a measure of how close similar values are to each other, independent of reference data [13, 33–35]. There was no significant difference in precision between PB starting sides and ending sides for any scanning pathway. In addition, there was no significant difference in precision between the starting sides and sides for FB for any scanning pathway.

The scan deviation at the starting side of PB showed the highest precision with scanning pathway B. Significant differences were observed in precision between the scanning pathways A and B, between pathways B and C. Müller et al. investigated the effect of three scanning pathways on optical impression accuracy using Trios® Scanner with a maxillary full-arch model [22]. In their study, after scanning the occlusal and palatal sides, the buccal side scan route showed the highest precision, which is consistent with the results of our study. Scanning pathways in the order of occlusal surface, palatal side, and buccal side were reported to eliminate the risk of subsequently increasing errors when using linear data acquisition over a longer distance. Therefore, regarding starting-side precision, it is believed that scanning pathway B displays similarly high precision compared with scanning pathway A, which first scans a wide range. The scan deviation of ending side PB showed the highest precision with scanning pathway D. Significant differences were observed in precision between the scanning pathways A and B, between
pathways A and D. Factors influencing deviation among the ending side molars include increased scan distance and scanning of the anterior teeth. Large deviations at the radial end of the scan data have been reported because of the accumulation of overlapping deviations in the anterior dental region [10]. The fact that anterior teeth are structurally simple makes accurate stitching of the data particularly difficult [6, 14]. It was suggested that reducing the scan range, such as for scanning pathways C and D, may reduce deviation in the anterior region compared with a wider scan. On the ending side, pathway D, which was scanned widely, showed higher precision than pathway A.

For FB, precision on the starting side was approximately the same as that of the ending side, and no significant difference was observed.

In addition, when comparing PB and FB, similar precision was shown on the starting side as was the case with trueness. However, in the case of PB, the precision of the ending side was lower than that of FB.

Trueness color map image deviation trends

Superimposed trueness data are displayed in color map format. As the starting side was considered as a standard for the superimposition for PB trueness, the starting side trueness mostly showed a range of ±50 µm among all the scanning pathways. For the ending side, the deviation mainly ranged from −150 to -450 µm on the occlusal surface and buccal cervical regions.

In past studies, it has been reported that TRIOS® shows the largest deviation in the molar region tended to underestimate the reference file marginally [34]. This is consistent with the results of our study.

The trueness of FB was in the range of +50 to +150 µm, with the majority of the deviation on the starting side. On the ending side, the deviation ranged from ±50 to ±250 µm. In addition, the degree of deviation was observed to be strong enough to tend toward molar distal regions. In many studies using superimposed color map images of full-arch, large displacements have been reported in both vertical and horizontal directions in the radial molar region of the ending side [4, 10, 14, 22, 28, 36]. It has also been reported that deviation to the occlusal surface increases owing to the strong effect of factors such as image overlap and still image skill [25]. Similarly, in this study, we believe that the deviation range for the ending side showed a strong tendency toward the vertical or horizontal displacement of the occlusal surface and cervical region, tending toward the distal region.

Clinical significance

In this study, the accuracy of full-arch could be evaluated on the ending side when two data sets were superimposed. On the ending side, the trueness of PB was 183.0 ~ 222.0 µm, and that of FB was 82.0 ~ 117.0 µm. The precision of PB was 83.5 ~ 134.0 µm, and that of FB was 48.5 ~ 54.0 µm. It has been reported that the accuracy of optical impression for a full arch teeth is within the acceptable range of 250 µm or less [26]. Thus, it was suggested that there was no issue with the reproducibility for jaws with teeth present.
In contrast, the accuracy of partial arch can be evaluated on starting sides where two data sets were superimposed. For the starting side, the trueness of PB was 89.0 ~ 106.0 µm and that of FB was 99.0 ~ 112.0 µm. The precision of PB was 28.0 ~ 44.5 µm, and that of FB was 41.0 ~ 52.0 µm, indicating a higher precision than that for full-arch. Thus, it was suggested that partial arch prosthesis range is more accurate than full-arch range. If the final prosthetic device is within the range of one jaw side, it is ideal to perform the scan as such.

Visual observation of color map images for trueness indicated that the starting side trueness for PB ranged between ± 50 µm and the starting side trueness for FB ranged from +50 to +150 µm. From these results, it can be inferred that, in the case of FB, the abutment teeth are expressed to a slightly greater extent.

In contrast, the trueness of ending side PB ranged from −150 to -450 µm, and the trueness of ending side FB ranged from ±50 to 250 µm. From these results, it can be inferred that one-sided prosthesis with better trueness may be superimposed by PB. Furthermore, if bilateral prosthesis was present, FB was shown to be preferential. As the color map was visually observed from one direction (buccal side) only, the actual displacement of the lingual side data is unclear. Therefore, it is necessary to observe from other directions in the future.

In addition, scan deviation results and color map image observations do not necessarily match. Scan deviations are expressed as absolute deviation. However, the color map image is in single-tooth units, with the largest color map trueness range as the representative value. Therefore, we need to evaluate the results of both scanning pathways for the trueness impact.

In this study, preparation of abutment teeth was not performed on the model because natural dentition was assumed. It has been reported that the shape of the prepared abutment teeth surface may affect the accuracy of the optical impression [32], and the scanning of mucosal and subgingival area is difficult [3, 21]. It is probably important to investigate the shape and margin of the abutment tooth, the deficiency mucosa situation.

**Conclusions**

In this study, two superimposition criteria of PB and FB were used for 3D data of optical impressions using four scan pathways. The trueness and precision of the starting side molar and ending side molar were evaluated. These experiments produced the following results:

1. The scanning pathway in this study were clinically applicable in the scanning time and amount of scan data.
2. The scanning pathways did not affect the trueness of the starting sides and ending sides both PB and FB.
3. The scanning pathways affected the precision of starting sides and ending sides with PB. Scanning pathway B was more precise on the starting side and scanning pathway D was more precise on the
ending side. With FB, the scanning pathway did not affect the precision for both starting sides and ending sides.

Abbreviations

IOS
Intraoral scanner
PB
partial-arch best-fit method
FB
full-arch best-fit method
RMS
root mean square

Declarations

Acknowledgment

The authors like to thank 3D! company for conducting the image analysis and the support during this study.

Author Contributions

All the authors made substantial contributions to the present study. SK, MY and TS contributed to conception and design, acquisition of data, analysis and interpretation of data; they were, moreover, involved in writing and editing the manuscript. SN statistically analyzed the data and was a major contributor in writing the manuscript. RH and HS revised the manuscript before submission. All authors read and approved the final manuscript.

Fundings

The present in vitro study was not funded or supported by any grants.

Availability of data and materials

Data are available from the corresponding author after approval by all authors.

Ethics approval and consent to participate

No Ethics Committee approval or consent to participate was requested, as the present was an in vitro study.

Consent for publication
Not applicable.

**Competing interests**

The authors declare that they have no competing interests.

**Author details**

Department of Fixed Prosthodontics, Tokyo Dental College, 2-9-18 Kandamisakicho Chiyoda-ku, Tokyo 101-0061, Japan

**References**


Figures
Figure 1

Scan environment. The reference model was set in a sitting position so that the occlusal plane was horizontal with the floor.
Figure 2

Four scanning pathways. Pathway A: Scan in the order of occlusal surface, buccal side, lingual side. Pathway B: Scan in the order of occlusal surface, lingual side, buccal side. Pathway C: Scan in a single sextant unit. Pathway D: Scan in S-shape for each tooth. mark is starting point (left second molar), mark is end point (right second molar).
Figure 3

Scan deviation with PB for each scanning pathway. (α) starting side, (β) ending side. The box plots represent the scan deviation between the five test scans data from the four scan pathways and the reference scan data (trueness).
Figure 4

**Scan deviation with FB for each scanning pathway.** (α) starting side, (β) ending side. The box plots represent the scan deviation between the five test scans data from the four scan pathways and the reference scan data (trueness).
Figure 5

Scan deviation with PB for each scanning pathway. (α) starting side, (β) ending side. The box plots represent the scan deviation between each combination of the five test scans data from the four scan pathways (precision).
Figure 6

Scan deviation with FB for each scanning pathway. (α) starting side, (β) ending side. The box plots represent the scan deviation between each combination of the five test scans data from the four scan pathways (precision).
Figure 7

Representative example of color-coded deviation maps (trueness) between the reference and digital models for PB. (α) starting side: The deviation range showed a range of ± 50 among all the scanning pathways, (β) ending side: The deviation range was –150 to –450 on the occlusal and buccal cervical regions.
Figure 8

Representative examples of color-coded deviation maps (trueness) between the reference and digital models for FB. (α) starting side: The deviation range mostly showed a range of +50 to +150 among all the scanning pathways, (β) ending side: The deviation range showed a scattered range of ±50 to ±250 among all the scanning pathways.