Dimensional and Occlusal Accuracy of a Novel Three-Dimensional Digital Model of Articulated Dental Arches

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Purpose: To develop a method for capturing the three-dimensional (3D) shapes of dental arches in a position relative to that of maximum intercuspation and to evaluate its dimensional and occlusal accuracy. ***Materials and Methods:*** The conventional custom-tray impression technique was used to capture detailed and dimensionally accurate impressions of individual teeth, and a modified bite-registration technique was used to register the relative positions of the maxillary and mandibular teeth in maximum intercuspation. It was hypothesized that this procedure may help to eliminate the occlusal inaccuracy caused by mouth opening–induced mandibular flexion. Two types of rigid frames (buccal and palatal) were used to prevent deformation of the interocclusal record. Their effects were tested on an articulated full-arch master cast and compared in terms of dimensional accuracy. In addition, the procedure was applied to a healthy volunteer to visually evaluate occlusal accuracy based on the form and distribution of the occlusal contacts. ***Results:*** The mean decrements of the dental arch width were 0.037 ± 0.017 mm and 0.269 ± 0.114 mm when using the palatal and buccal frames, respectively. The dimensional accuracy of the palatal frame was comparable to that of the custom-tray impression technique. The form and distribution of the occlusal contacts between the 3D dental arches were similar to those observed in the transilluminated image of the interocclusal record, indicating the occlusal accuracy of this method. ***Conclusion:*** The dimensional and occlusal accuracy of the method proposed here is suitable for clinical application when used in combination with the palatal frame. *Int J Prosthodont 2013;26:282–287. doi: 10.11607/ijp.2995*

The custom-tray impression technique is recommended as a reliable method of taking impressions to fabricate fixed dental prostheses because it enables the clinician to capture a detailed and dimensionally accurate impression of the abutments as well as the residual teeth.[1–3] However, prostheses fabricated using this procedure require a considerable amount of occlusal adjustment during insertion. The same holds true for the optical impression technique[4]; however, the detailed three-dimensional (3D) shapes of the abutments and other teeth can be captured accurately by using an intraoral scanner.[5]

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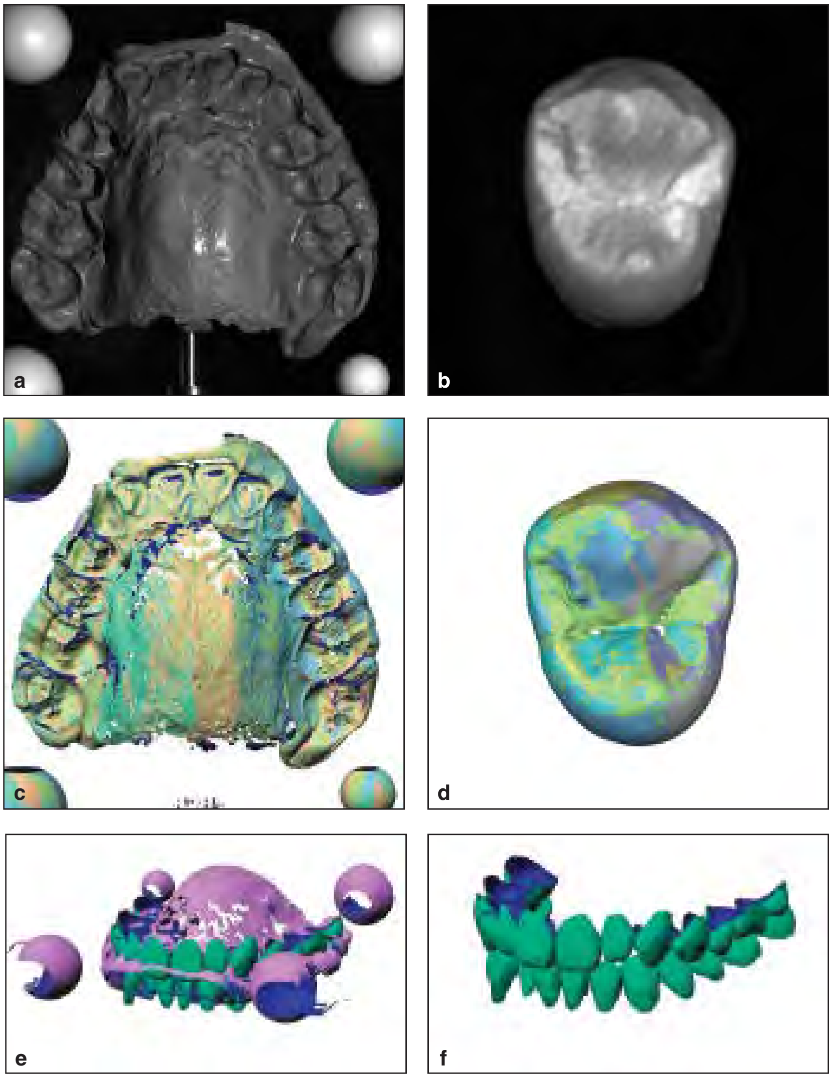
The abovementioned drawback may be caused by the inaccuracies in the occlusal relationship between the maxilla and mandible. Jaw opening, which is required during the process of obtaining an impression, causes flexion of the mandible and deformation of the mandibular dental arch.[6–8] These changes in the mandible subsequently alter the occlusal relationship between the arches and increase the vertical dimension of occlusion, which has been reported to reach up to 0.2 mm using the custom-tray impression technique.[9]

The dual-arch impression technique[10] would be a reasonable alternative for achieving occlusal accuracy[11] because it enables the clinician to make simultaneous impressions of both the maxilla and mandible without jaw opening. However, its usefulness is practically limited to a sectional impression.

This study aimed to develop a method of capturing accurate 3D shapes of the entire maxilla and mandible in a position relative to that of maximum intercuspation. In this new method, the detailed and dimensionally accurate shape of an individual tooth was registered by means of the conventional custom-tray impression technique, and the relative position of



Figs 1a to 1f Fabrication method of 3D dental arches in occlusion. The 3D shapes of the interocclusal record **(a)** and the stone cast of the maxillary right first premolar **(b)** were captured using the 3D optical scanner. Four spheres were set around the record to subserve the alignment of the data of the maxillary and mandibular surfaces of the interocclusal record. The 3D shapes of the interocclusal record **(c)** and the stone cast **(d)** comprised 11 and 6 datasets (each dataset is indicated by a different color) from different viewpoints, respectively. The 3D shapes of the individual teeth were aligned with those of the interocclusal record **(e)**. After all 3D shapes of the individual teeth were aligned, the 3D dataset of the interocclusal record was deleted to fabricate the 3D shape of the dental arch in a position relative to that of maximum intercuspation **(f)**.

the tooth within the dental arch, as well as the maxilla and mandible, were registered by means of the interocclusal recording technique. The 3D shapes of the individual teeth and the interocclusal record were captured using an optical scanner and aligned using computer-aided design (CAD) software to develop the shapes of the dental arches in occlusion. The accuracy of this method was also evaluated.

Materials and Methods

Capturing 3D Shapes of the Arches in Maximum Intercuspation

Impressions of the maxillary and mandibular dentitions (Fig 1) were taken individually with the conventional custom tray, which was composed of self-curing resin material (Tray Resin II, Shofu) and polysiloxane impression material (Fusion II, extra-wash and wash type, GC). The stone casts (Fig 1b) were fabricated using type IV die stone (New Fuji-Rock, GC) and divided into individual tooth pieces. The 3D shapes of the individual teeth (Fig 1d) were then captured using a 3D optical scanner (Comet Vario-Zoom, Steinbichler Optotechnik), which was based on the fringe projection technique. The nominal measurement error of the scanner was ± 0.02 mm.

The interocclusal record (Fig 1a) at maximum intercuspation was obtained using the custom-made frame to eliminate deformation of the interocclusal record and the bite-registration material (a trial product, CBS-006, GC), together with the adhesive agent for polysiloxane impression materials provided by the same manufacturer. The bite-registration material had been specially designed to have suitable material properties for optical scanning. It had a Shore-A hardness of 90, dimensional accuracy of –0.1%, consistency of 34 mm, and working time of 60 seconds.

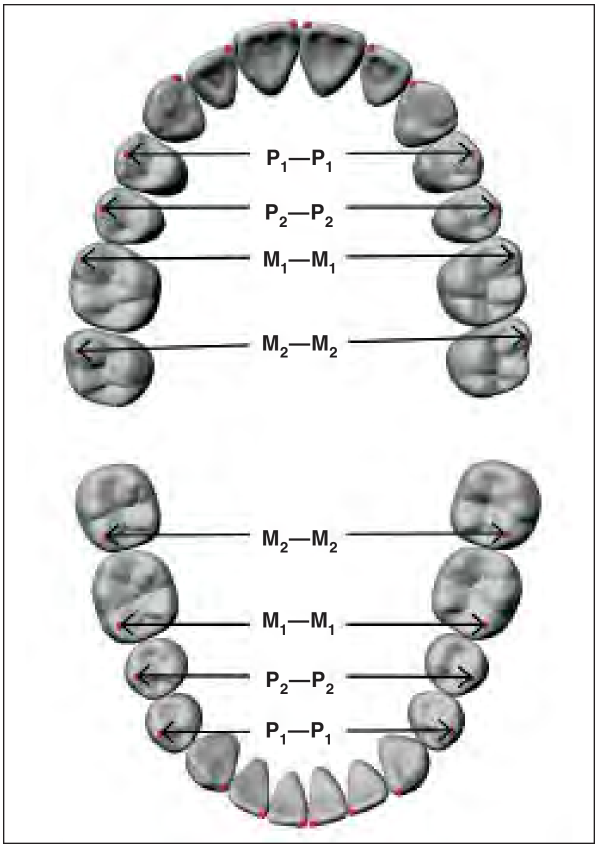


Fig 2 Parameters for dimensional accuracy evaluation. Landmark points were indicated on the buccal cusp tips of the premolars and the mesiobuccal cusp tips of the molars prior to the alignment of the shapes of the individual teeth with those of the interocclusal record. The distances between the landmark points of the first premolars, second premolars, first molars, and second molars were defined as P_1–P_1, P_2–P_2, M_1–M_1, and M_2–M_2, respectively.

The 3D shape of the interocclusal record (Fig 1c) was also captured using the same optical scanner.

Multiple views were taken from different angles to obtain the shape of the entire surface of the individual teeth and the interocclusal record. The interocclusal record, as well as four spheres, was set to the rectangular frame (Fig 1a) and rotated around the anteroposterior axis of the dental arch by 30 degrees each in front of the optical scanner to maximize the captured surface area. The views were then processed to convert all aspects into a single and nonredundant 3D shape dataset using the following functions of the 3D CAD software package (PolyWorks, version 10, InnovMetric Software): the alignment function to transform individual views into a common coordinate space by best fitting the views, and the merge function to integrate the aligned views into a single 3D dataset and to reduce the overlapping area of the views. The shapes of the spheres were helpful in facilitating the alignment.

The 3D shape dataset of the individual teeth was aligned one-by-one with that of the interocclusal record (Fig 1e) using the alignment function of the same software. During this process, the portions of the occlusal surfaces that were involved in the shapes of both individual teeth and interocclusal record were best fitted. Once all 3D data for the individual teeth were aligned, the interocclusal record data were deleted to complete the dental arch data in occlusion (Fig 1f).

Dimensional Accuracy Evaluation

An articulated dental cast was used as the master cast. To avoid attrition of surface form by repetitive registration of the interocclusal record, the master cast contained 28 artificial melamine teeth (simple root tooth model, Nissin). Interocclusal records of the master cast were obtained as follows: *(1)* a frame (described later) was fitted on the master cast; *(2)* bite-registration material was injected onto the occlusal surface of the maxillary teeth and into the space between the frame and the teeth; *(3)* the articulator was closed and soaked in water at a temperature of 37°C for 2 minutes; and *(4)* the interocclusal record was carefully removed from the master cast together with the frame. The 3D shape dataset of the maxilla and mandible was then obtained using the abovementioned method. The landmark points (Fig 2) used to investigate dimensional accuracy were identified and indicated on the buccal cusp tips of the premolars and the mesiobuccal cusp tips of the molars prior to the alignment of the shapes of the individual teeth with those of the interocclusal record. This technique eliminated errors associated with redefining the landmark points on the different shapes.

Two custom-made frames (buccal and palatal) were designed and fitted onto the master cast and their performance was compared with regard to the elimination of deformation of the interocclusal record. The buccal frame ran around the buccal surface of the dental arch. The palatal frame ran around the palatal and lingual surfaces of the arch and was integrated with the palatal plate; its retention force was expected to maintain the proper position of the frame in the mouth. Both frames were fabricated using heat-curing resin material (Acron, no. 5; GC).

The measurement was repeated using either the buccal or the palatal frame six times each. As a standard for comparison, the occlusal surface of the master cast was scanned in the occlusal view, and the dental arch shape was fabricated by aligning the shapes of the individual teeth with the shape of the master cast using the same method described above.

Table 1 Dimensional Accuracy of the Proposed Method

	Maxilla				Mandible			
Parameter	P_1–P_1	P_2–P_2	M_1–M_1	M_2–M_2	P_1–P_1	P_2–P_2	M_1–M_1	M_2–M_2
Distance (mm)	44.067	50.049	54.929	57.482	37.757	43.196	47.399	51.554
Deformation (mm)*								
Palatal frame	−0.006 (0.004)	−0.034 (0.009)	−0.040 (0.010)	−0.037 (0.011)	−0.043 (0.010)	−0.043 (0.014)	−0.050 (0.012)	−0.046 (0.019)
Buccal frame	−0.156 (0.034)	−0.249 (0.049)	−0.309 (0.075)	−0.403 (0.109)	−0.135 (0.028)	−0.219 (0.046)	−0.290 (0.065)	−0.394 (0.106)

*Deformation represents the mean (standard deviation) difference between the distances measured on the master casts and captured dental arches.

The distances between the landmarks on the same tooth type (Fig 2), ie, the dental arch widths, were measured in the maxilla and mandible between the first premolars (P_1–P_1), second premolars (P_2–P_2), first molars (M_1–M_1), and second molars (M_2–M_2). The dental arch widths for the shapes obtained with the buccal and palatal frames were compared with those obtained directly from the master cast.

Evaluation of Interocclusal Accuracy

To visually test the occlusal accuracy of the method, custom-tray impressions of the dental arches and their interocclusal records were made from a subject who had complete natural dentition (27-year-old woman). The distances between the maxillary and mandibular 3D arches obtained from the subject were calculated using the CAD software. Portions of the occlusal surface where the distance between the maxillary and mandibular teeth was less than 0.06 mm were identified. The distribution of these portions was compared with that of the transilluminated image obtained by taking a picture of the same interocclusal record using a light box.

The protocol of the in vivo component of this study was approved by the Human Ethics Committee of Tohoku University Graduate School of Dentistry and was conducted in accordance with the ethical principles for medical research involving human subjects outlined in the Declaration of Helsinki. The participant provided written informed consent before the study.

Statistical Analysis

The Mann-Whitney *U* test was used to compare the performance of the buccal and palatal frames with respect to the elimination of deformation of the interocclusal record. The statistical significance level was set at $P < .05$.

Results

Time and Effort Required to Fabricate Arch Shapes

The time and effort required for the two impression techniques, ie, the custom-tray impression technique and the modified interocclusal recording technique, were approximately the same as those required for the conventional method. It took 40 seconds per view to capture the shape using the optical scanner. The number of views required to capture the shape of the whole surface depended on the complexity of the object, ranging from 5 to 7 views for an individual tooth and from 10 to 12 views for the maxillary and mandibular surfaces of the interocclusal record.

Dimensional Accuracy

The dental arch width between the bilateral posterior teeth of the master cast ranged from 37.757 (P_1–P_1 in the mandible) to 57.482 mm (M_2–M_2 in the maxilla). The fabricated 3D dental arch shapes had decreased arch widths at all measuring points. The decrements were 0.037 ± 0.017 mm (mean ± SD) and 0.269 ± 0.114 mm in those cases where the interocclusal records were registered by using the palatal and buccal frames, respectively. Significant differences were observed between these values (Mann-Whitney *U* test, $P < .01$; Table 1).

Interocclusal Accuracy

The form and distribution of the occlusal contacts of the subject were clearly indicated by the transparent areas of the transilluminated image of the interocclusal record (Fig 3). They were similar to the occlusal contacts between the maxilla and mandible calculated using the CAD software. The maxillary and mandibular teeth overlapped in eight pairs of opposing

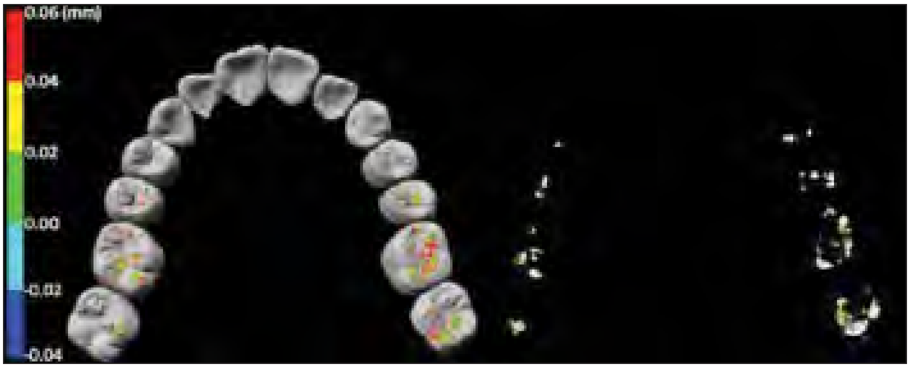


Fig 3 Occlusal contacts of the 3D dental arch shapes and the interocclusal record. Occlusal contacts calculated from the 3D dental arch shapes *(left)* were compared with the transparent areas, which were observed in the transilluminated image of the interocclusal record *(right)*. The color map shows that the distance between the maxilla and mandible was less than 0.06 mm. The maxillary tooth made overlaps into the corresponding mandibular tooth in eight pairs of opposing teeth; of these, the overlaps exceeded 0.02 mm in 3 pairs of opposing teeth (the right second premolars, right second molars, and left first premolars). The greatest overlap (0.031 mm) was observed at the right second molar.

teeth as a result of the interocclusal inaccuracy; however, the maximum extent of the overlaps was no more than 0.031 mm (between the right second molars). In addition, the extent of the overlaps was 0.02 mm or less for five of these eight pairs.

Discussion

In spite of the remarkable improvement in dental impression materials, the accuracy of fabricated fixed restorations remains inadequate. Much effort is needed for occlusal adjustment when restorations are seated in the mouths of patients. Occlusal inaccuracy of the articulated dental casts and dimensional inaccuracy of dental casts are the leading causes of this discrepancy. Remediation of these inaccuracies is an absolute prerequisite to ensure that fabricated dental restorations are set "as machined" in computer-aided design/computer-assisted manufacture (CAD/CAM) dentistry. Thus, this study focused exclusively on this matter.

The results reveal the excellent accuracy of the proposed method. First, the occlusal contacts observed in the interocclusal record were successfully reproduced in the 3D shapes. DeLong et al[4] captured the 3D shapes of the dental casts as well as the interocclusal record, aligned the shapes with each other, and found that the number of occlusal contacts of the aligned 3D dental models was 16% less than that visually evaluated on the transilluminated image of the interocclusal record. Their optical scanning and alignment methods were almost identical to those of the present study, and the main difference between the two studies is that the dental arch model was divided into individual teeth in the present study. Therefore, deformation of the dental arch due to flexion of the jaw may be the main cause of occlusal inaccuracy of the aligned dental models of the DeLong study.

Second, although occlusal inaccuracy was indicated by overlaps between the 3D shapes of the maxilla and mandible, the extent of the overlaps (maximum, 0.031 mm) was less than one-sixth of the increment of occlusal vertical dimension of the articulated casts reported for the custom-tray impression technique.[9] The inaccuracy and irregularity of the surface of the 3D teeth probably caused these overlaps. Moreover, the spatial resolution of the optical scanner used in the present study was 0.075 mm, and its nominal error was ± 0.02 mm, which may have caused overlaps of up to 0.04 mm.

Third, the dimensional accuracy of the proposed technique, which was evaluated using the reproducibility of the dental arch width (narrowing of 0.037 ± 0.017 mm), was almost identical to that of the conventional custom-tray impression technique, which uses a tray made of self-cured acrylic resin (with an expansion of approximately 0.043 mm, according to Gordon et al[2]), although both methods result in reciprocal changes. The size of the error was again within the acceptable range for indirect restorations. Because superior dimensional accuracy has been reported when using a tray made of thermoplastic,[2] with the difference in accuracy attributed to the differences in the rigidity of the tray material, using harder material for the palatal frame is considered to help improve the dimensional accuracy of the proposed method.

The obvious drawback of this method is the cumbersome procedure required to fabricate the stone cast of the individual teeth, capture the 3D shapes of their surfaces, and align them with the shape of the interocclusal record. However, equal occlusal accuracy can be achieved with less effort by subdividing the 3D shape of the dental cast into those of the individual teeth and by aligning these individual shapes with those of the interocclusal record using CAD software.

Conclusion

The accuracy of an optical impression is reported to be similar to that of a conventional impression. If the optical impression can also be accurate in vivo, then the custom-tray impression technique can be replaced by optical impression of the occlusal surfaces of the individual teeth. Similarly, the interocclusal recording technique can be replaced by capturing the labiobuccal surfaces of the dentition in the position of maximum intercuspation using an optical scanner. This technique may help further reduce the effort required, although the basic concept of the method remains the same.

Acknowledgments

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References

1. Eames WB, Sieweke JC, Wallace SW, Rogers LB. Elastomeric impression materials: Effect of bulk on accuracy. J Prosthet Dent 1979;41:304–307.
2. Gordon GE, Johnson GH, Drennon DG. The effect of tray selection on the accuracy of elastomeric impression materials. J Prosthet Dent 1990;63:12–15.
3. Boulton JL, Gage JP, Vincent PF, Basford KE. A laboratory study of dimensional changes for three elastomeric impression materials using custom and stock trays. Aust Dent J 1996;41:398–404.
4. DeLong R, Knorr S, Anderson GC, Hodges J, Pintado MR. Accuracy of contacts calculated from 3D images of occlusal surfaces. J Dent 2007;35:528–534.
5. Ender A, Mehl A. Full arch scans: Conventional versus digital impressions: An in-vitro study. Int J Comput Dent 2011;14:11–21.
6. Regli CP, Kelly EK. The phenomenon of decreased mandibular arch width in opening movements. J Prosthet Dent 1967;17:49–53.
7. Goodkind RJ, Heringlake CB. Mandibular flexure in opening and closing movements. J Prosthet Dent 1973;30:134–138.
8. Burch JG, Borchers G. Method for study of mandibular arch width change. J Dent Res 1970;49:463.
9. Matsushita K. A study on occlusal accuracy of cast crown: The changes of occlusal height of full cast crown by the fabrication steps. Nihon Hotetsu Shika Gakkai Zasshi 1982;26:250–266.
10. Wilson EG, Werrin SR. Double arch impressions for simplified restorative dentistry. J Prosthet Dent 1983;49:198–202.
11. Parker MH, Cameron SM, Hughbanks JC, Reid DE. Comparison of occlusal contacts in maximum intercuspation for two impression techniques. J Prosthet Dent 1997;78:255–259.

Literature Abstract

The prevalence of dentin hypersensitivity in general dental practices in the Northwest United States

This cross sectional study aimed to investigate the prevalence of dentin hypersensitivity in general dental practices as well as associated risk factors. A total of 787 adult patients from 37 general dental practices within the Northwest Practice-based Research Collaborative in Evidence-basedDENTistry (PRECEDENT) were asked to complete a survey about the presence of pain in the teeth and gingiva. The investigators did a clinical examination to exclude other sources of pain. Besides using a visual analog scale for the pain level, the Seattle Scales in response to a 1-second air blast was also used. Generalized estimating equation log-linear models were used to estimate the prevalence and the prevalence ratios. A 12.3 percent prevalence of dentine hypersensitivity was found, in which those with hypersensitivity had a mean of 3.5 hypersensitive teeth. There was increased prevalence of dentine hypersensitivity in the 18- to 44-year-old age group compared with those 65 years and above, in women than in men, in those with gingival recession and in those who have performed at-home tooth whitening. No association was found between dentine hypersensitivity and obvious occlusal trauma, noncarious cervical lesions, or aggressive toothbrushing habits.

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