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ORIGINAL ARTICLES

Registration error for integration between dental model and CT digital data

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The purpose of this study was to investigate the registration error of the method for integration between the dental model and CT digital data, and to present a three-dimensional (3D) digital dental model with tooth root morphology. Three radiopaque copper triangle-shaped sheets were attached to the palate of the phantom jaw, which comprises parts of the ready-made phantom for radiographic examination training. The upper dental model was scanned using a 3D surface imaging device. The phantom was also radiographed using a CT scanner. The dental model and CT digital data were integrated according to the contact point between the bilateral upper central incisors, the bilateral canine cusp tips, the buccal cusp tips of the bilateral second premolars, and the mesiobuccal cusp tips of the bilateral first molars using a 3D imaging software program. The distances of the corresponding points between the dental model and CT digital data for the 9 vertex points of the copper triangle-shaped sheets on the integrated image were measured. All dimensions were measured five times by one of the authors with a minimum interval of one day between measurements. The mean and standard deviation of the distances of the corresponding points between the dental model and CT digital data were 0.59 and 0.19 mm, respectively. The results suggest that the dental model and CT digital data were integrated with acceptable accuracy for orthodontic clinical use.

Key words : 3D, digital dental model, tooth root morphology

Introduction

Tooth alignment and the occlusal relationship between the upper and lower dentition have been evaluated using dental models, which are part of the routine examination for an orthodontic diagnosis. However, these models do not show the tooth root morphology. If such information were included in the model, it would be useful for determining the direction of the tooth axis.

The three-dimensional (3D) direction of the tooth axis has been evaluated using computed tomography (CT)[1-3]. However, CT cannot show the tooth morphology along the occlusal surface, because the upper and lower imaging data are connected at the occlusal surfaces, and the upper occlusal surface cannot be distinguished from the lower one.

The occlusal surface is examined in detail using a dental model. Therefore, in orthodontic practice it is important to integrate the dental model image with the CT image. The dental model and CT images have been merged using several methods[4-10]. Integrating the dental model and CT data can reveal the tooth crown and root position as well as the morphology.

The purpose of this study was to investigate the registration error of the method for integration between the dental model and CT digital data, and to present a 3D digital dental model with tooth root morphology.

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Materials and Methods

The subject was a devised phantom human jaw comprising parts of the ready-made phantom for radiographic examination training (Kyoto Kagaku, Co. Ltd., Kyoto, Japan). Three radiopaque copper triangle-shaped sheets were attached to the palate of the phantom. The dental impression of the phantom upper jaw was taken, and a dental model was made from the dental impression. The upper dental model was scanned using a 3D surface imaging device (3Shape R700 Scanner; 3shape, Copenhagen, Denmark). The phantom was also radiographed using a CT scanner (SomatomEmotion6; Siemens AG, Munich, Germany) (Figure 1). The X-ray tube voltage and current were 130 kV and 25 mA, respectively. Slice thickness was 0.6 mm with a one pixel size of 0.35 mm. The dental model and CT digital data were transferred to a personal computer (HP Z210 SFF Workstation; Hewlett-Packard Company, San Francisco, CA, USA). From the CT dataset, upper jaw structures were segmented on the basis of a threshold CT value, which was determined as -200 Hounsfield Unit (HU). The dental model and CT digital data were integrated according to the contact point between the bilateral upper central incisors, the bilateral canine cusp tips, the buccal cusp tips of the bilateral second premolars, and the mesiobuccal cusp tips of the bilateral first molars (Figure 2) using a 3D imaging software program (Body-Rugle, Medic Engineering, Kyoto, Japan).

The distances of the corresponding points between the dental model and CT digital data for the 9 vertex points of the copper triangle-shaped sheets on the integrated image were measured (Figure 3). All dimensions were measured five times by one of the authors with a minimum interval of one day between measurements. The mean and standard deviation of the five values were then determined.

Results

The distances of the corresponding points between the dental model and CT digital data are shown in Table 1. The mean and standard deviation of the distances of the corresponding points between the dental model and CT digital data on the integrated image were 0.59 and 0.19 mm, respectively. The registration error value was within 1.00 mm in the most locations of the dental model and was around 5.00 mm on the cervical region of the tooth (Figure 4). We can present a 3D digital dental model with tooth root morphology (Figure 5).

Discussion

The dental model and CT digital data were integrated in the present study. Several methods for integrating images have been reported in previous studies using the reference device[4,7,9] and anatomical structures[8,10] for registration. Whereas the registration technique using the reference

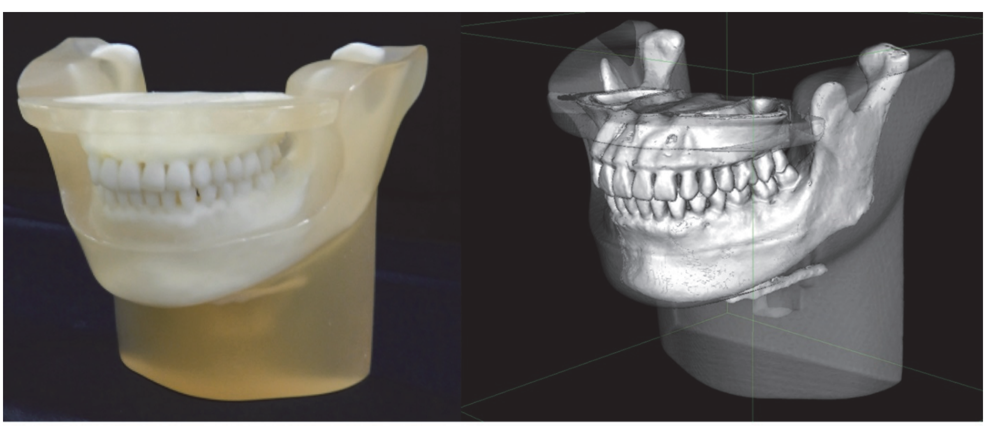
A B

Figure 1. A: The devised phantom human jaw, B: CT digital data of the phantom.

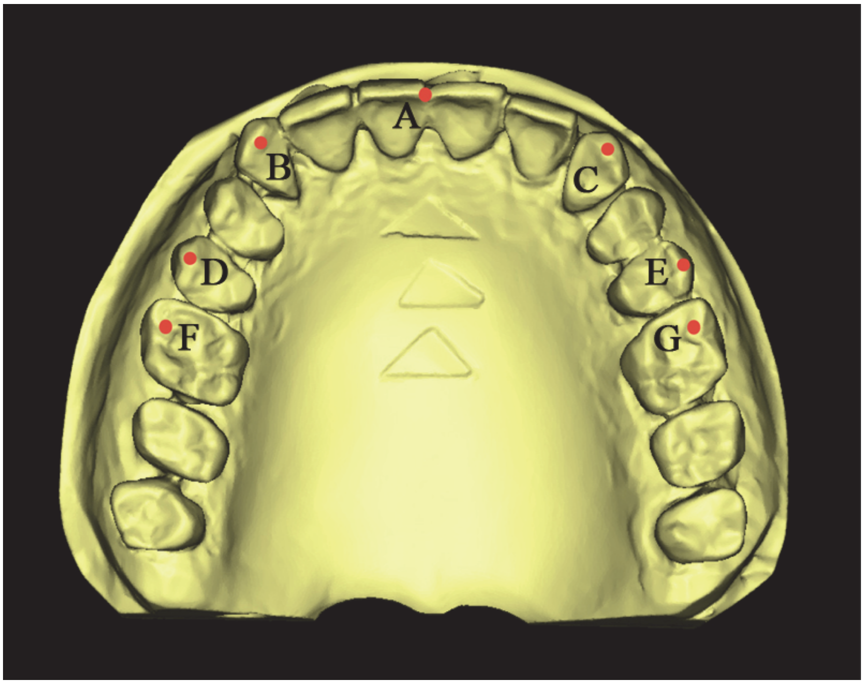

Figure 2. The 7 points used for registration between the dental model and CT images. (A, the contact point between the bilateral upper central incisors; B and C, the bilateral canine cusp tips; D and E, the buccal cusp tips of the bilateral second premolars; F and G, the mesiobuccal cusp tips of the bilateral first molars)

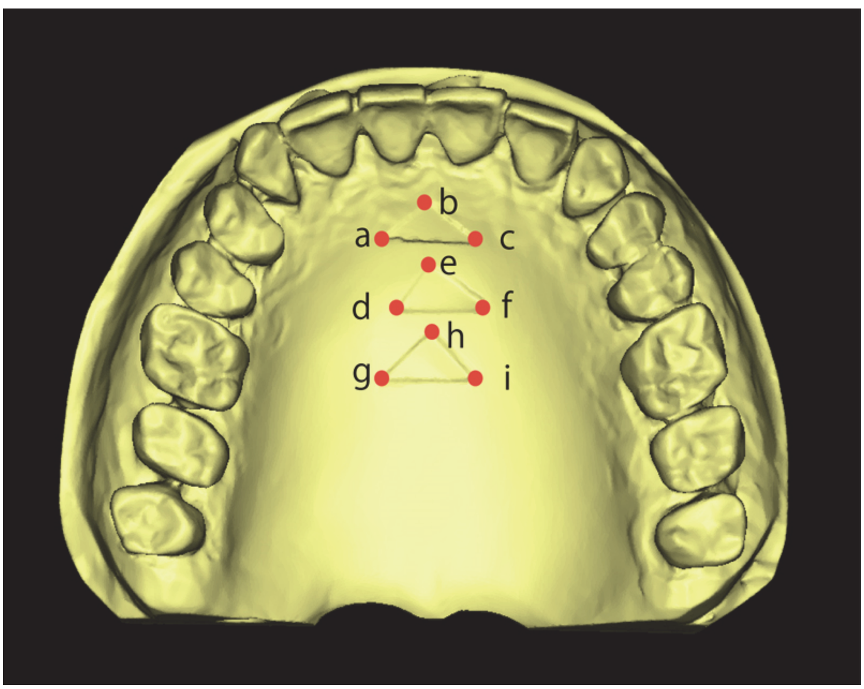

Figure 3. The 9 vertex points (a, b, c, d, e, f, g, h, and i) of the triangle-shaped sheet attached to the dental model for evaluating the accuracy.

	Registration error (mm)	
Point	Mean	S.D.
a	0.39	0.24
b	0.56	0.15
c	0.43	0.19
d	0.72	0.08
e	1.04	0.24
f	0.57	0.11
g	0.63	0.11
h	0.44	0.17
i	0.50	0.09
9 points	0.59	0.19

Table 1. The distances of the corresponding points between the dental model and CT digital data for the 9 vertex points of the copper triangle-shaped sheets on the integrated image

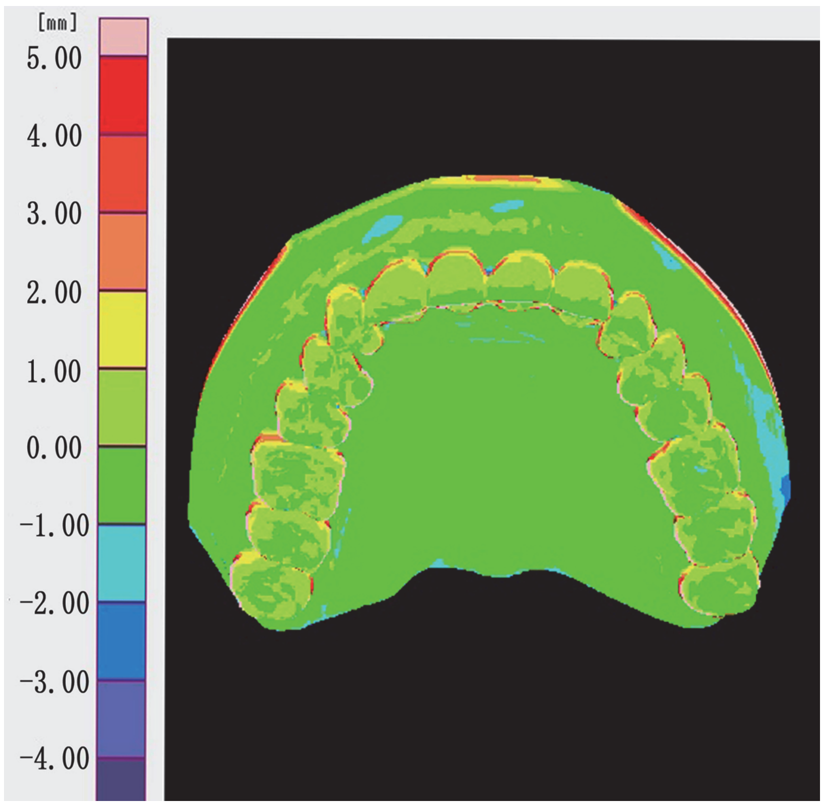

Figure 4. The distance between the dental model and CT images after integration. Warm colors (yellow, orange, and red) indicate positive change, and cold colors (blue and purple) indicate negative changes. Green indicates no change. (Positive change means the dental model image is located in front of the CT image and negative change means the dental model image is located behind the CT image.)

device is complicated, the present technique using the anatomical structure is considered quite simple. However, the anatomical structure has morphological variation, so the registration technique should be applied to various cases in future studies. Regarding the technical procedure for registration, the present study used a point-based method of registration. A previous study showed that surface-based registration is more reliable than point-based registration as superimposition[10]. The surface-based

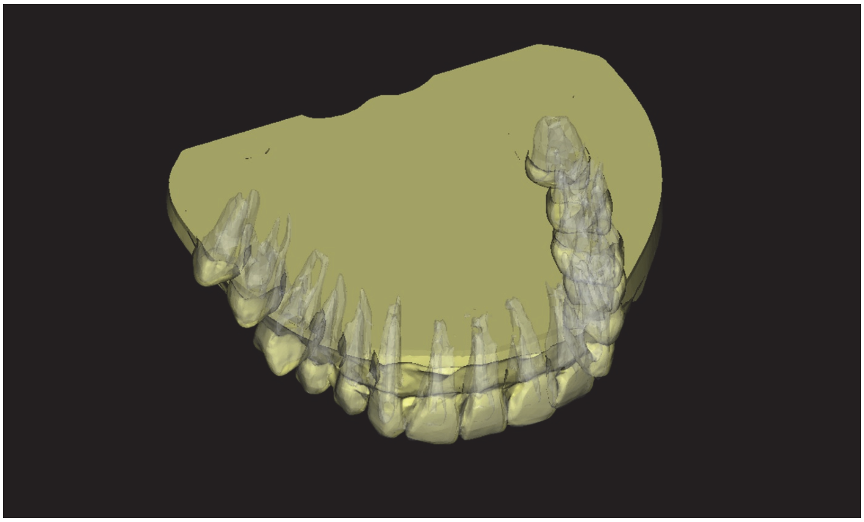

Figure 5. The integrated 3D images between the dental model and CT digital data (yellow: dental model, white: CT).

registration technique might therefore be preferred to the point-based registration technique for the integration of the dental model and CT data. In the present study, we did not adopt the surface-based registration technique because it is complicated. On the points for estimation of errors, we used the 9 points which are around midline of palate because there are few common points between dental model and CT digital data.

Regarding the clinical applications, integrating a dental model and CT images has been applied to implant placement[6)] and orthognathic surgery[9)]. In orthodontic practice, the integrated image may be useful for making an orthodontic diagnosis, developing a treatment plan, and determining treatment procedures. Using the integrated image, the spatial relationship between the tooth crown and root could be determined[11,12)]. As the tooth should be moved in consideration of the root position, the integrated image may be useful for performing indirect bonding techniques[13,14)]. In addition, the integrated image may be useful for mini-screw placement[15-17)] and planning treatment for impacted teeth[12,18)] in orthodontic practice. The brace must be placed accurately so that the tooth can be moved according to the orthodontic treatment plan. For bonding braces in the mouth, the orthodontists need to predict the tooth axis from the tooth crown[19)] and the present 3D digital dental model with tooth root morphology could be useful for orthodontic practice. The mean registration error value of 0.59 mm in the present study is acceptable for orthodontic clinical use. The registration error value on the cervical region of the tooth was around 5.00 mm but it is not necessary to identify the detail of the cervical region.

Conclusion

The dental model and CT digital data were integrated with acceptable accuracy for orthodontic clinical use.

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口腔模型とCTデジタルデータの統合誤差

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本研究の目的は，口腔模型とCTデジタルデータの統合誤差を検討し，歯根形態を含む三次元デジタル口腔模型を提示することである．レントゲン検査のトレーニングに使用するファントムの一部からなるファントムを被写体として用い，その口蓋上にＸ線不透過性の三角形銅板を３枚貼付した．ファントムの上顎歯列模型から，口腔模型三次元計測装置を用いて口腔模型デジタル画像を取得した．また，同ファントムのCT画像を撮影した．取得した口腔模型とCT画像のデジタルデータを，三次元画像分析ソフトウェアを用いて，両側中切歯間接触点，両側犬歯尖頭頂，両側第二小臼歯頬側咬頭頂，両側第一大臼歯近心頬側咬頭頂を基準として統合した．統合後の画像上で，口蓋上に貼付した３枚の三角形銅板の頂点について，口腔模型とCT画像の対応する点間の距離を計測した．すべての計測は一日以上の間隔をおいて５回行った．口腔模型とCT画像間の距離の平均と標準偏差は，それぞれ，0.59mmと0.19mmであった．口腔模型デジタル画像とCT画像は，矯正歯科臨床において許容できる精度で統合できることが示唆された．

キーワード：三次元，デジタル口腔模型，歯根形態

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