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Influence of orthodontic bracket block-out materials on superimposition errors when substituting scanned dental imaging data onto computed tomography images

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ABSTRACT

Purpose: The study was performed to examine the error associated with image superimposition when computed tomography (CT) images of the dental region are substituted with dental scan data, according to the block-out material used in dental impressions.

Materials and Methods: A typodont model was created by bonding orthodontic brackets to teeth on plaster dental stones using melted dental base-plate wax. In the experiment, 2 groups were compared: one using wax and the other using putty as the block-out material to prevent tearing of the impression material during the acquisition of dental impressions. In the wax group, dental cast digital data were superimposed onto the CT data of the typodont model using a tooth occlusal surface-based registration method. In the putty group, a surface-based registration method was used that incorporated not only the occlusal surfaces of the teeth, but also the area where the radiopaque putty covered the orthodontic brackets. The absolute value of the error on the dental surfaces was measured for comparisons.

Results: Analysis of the scanned areas used for replacement in dental CT images revealed fewer superimposition errors when considering only the tooth occlusal surface area, excluding the area containing putty impression material.

Conclusion: The clinical recommendation is to block out the orthodontic bracket with radiolucent wax when obtaining dental impressions. Furthermore, only dental occlusal surface-based registration should be used for the superimposition and replacement of the CT image of the dental area with scanned data from a dental cast model. ***(Imaging Sci Dent 2024; 54: 319-26)***

KEY WORDS: Tomography, X-Ray Computed; Radiography, Dental, Digital; Dental Occlusion; Subtraction Technique

Introduction

Developments in digital dentistry have led to advancements in computer-assisted surgical simulation, which enable accurate diagnosis and the formulation of appropriate treatment plans for surgery involving the maxillofacial skeleton.[1,2] Correct reproduction and analysis of images of the facial bones and teeth are essential for computer-aided surgical simulations and the computer-aided design/computer-aided manufacturing (CAD/CAM) of surgical devices.[3,4]

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Computed tomography (CT) imaging is utilized for the reproduction of the maxilla and teeth, reflecting the 3-dimensional (3D) morphology of these structures. While reproducing an accurate 3D image of the dental area is crucial, image artifacts introduced by dental materials such as filling components, dental prostheses, and orthodontic brackets can interfere.[5,6] The use of digital technology in dental treatments also necessitates the acquisition of accurate dental data.

Preoperative simulation is crucial when employing a surgical guide device in maxillofacial surgery that relies on teeth or occlusal information to establish the positional relationships between the mandible and maxilla. Analog casts can be readily utilized to plan the dental occlusion of the entire arch. Additionally, accurate dental data, including the occlusal relationships between teeth, are necessary for the 3D

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printing of the surgical device. Researchers have explored methods that involve superimposing digital dental images onto CT scans to more accurately depict the craniofacial structure, including the teeth, in 3 dimensions. In these approaches, the image of the dental area is removed from the CT scan and replaced with more accurate digital dental images,[7] obtained by scanning a dental cast or impression.[6,8,9]

Existing methods for acquiring intraoral dental data have been refined for use in tooth preservation and prosthetic treatments. However, in the context of orthognathic surgery—which typically includes orthodontic treatment—capturing an intraoral impression can be challenging due to the presence of orthodontic appliances, and direct intraoral scanning may not be feasible. Scanning dental data directly might be more straightforward than creating a dental cast model from an intraoral impression. When taking an intraoral impression from an orthodontic patient, the orthodontic appliances are covered with a material such as wax to prevent them from tearing or deforming the impression material. Consequently, the dental cast can deviate from the patient's true intraoral structure. Limited research is available regarding the superimposition error that can arise when the patient's CT data and the dental cast differ. Nevertheless, during impression-taking for a tooth cast, block-out is essential to avoid deformation of the impression material. CT images can also be affected by the material used, leading to variable errors when superimposing digital tooth scan data onto CT images. Research is scarce regarding how the type of material used for blocking out orthodontic brackets affects the substitution of dental data. In the replacement of the CT image of the tooth area with a more detailed digital image, the alignment of the digital tooth data with the CT scan is crucial. With surface-based registration, it is vital to determine whether increasing the reference surface area impacts the accuracy of the image overlap.

This study aimed to quantify the error of the superimposition method according to the block-out material used during dental impression acquisition, specifically when dental area CT images are substituted with dental scan data.

Materials and Methods

Typodont model

A typodont model was created using teeth from a cadaver's dry skull (Skulls Unlimited International Inc., Oklahoma City, OK, USA) and plaster dental stones (Mutsumi Chemical Industries, Yokkaichi, Japan). The model was constructed by melting dental base-plate wax (Plate Wax for Technologic Dentistry; WAXCO, Daegu, Korea). This dental model was then scanned with a 3D optical scanner (Rexcan DS2; Solutionix, Seoul, Korea) to measure error (Fig. 1). Orthodontic brackets (3M Unitek; 3M Oral Care, St. Paul, MN, USA) were bonded to the teeth on the dental model to align with clinical practice (Fig. 2).

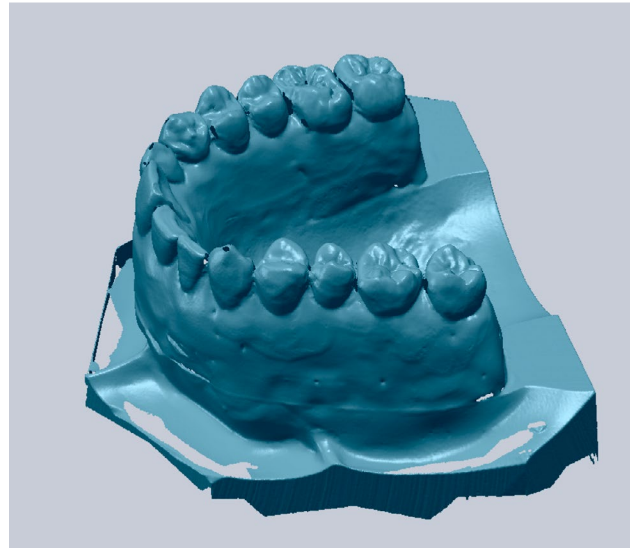

Fig. 1. Digital data image of a typodont model. The model was scanned using a 3-dimensional optical scanner.

Fig. 2. Typodont model constructed with teeth from a cadaver dry skull, set in plaster dental stone using melted dental base plate wax. Orthodontic brackets were bonded to the teeth of the model, mirroring clinical practice.

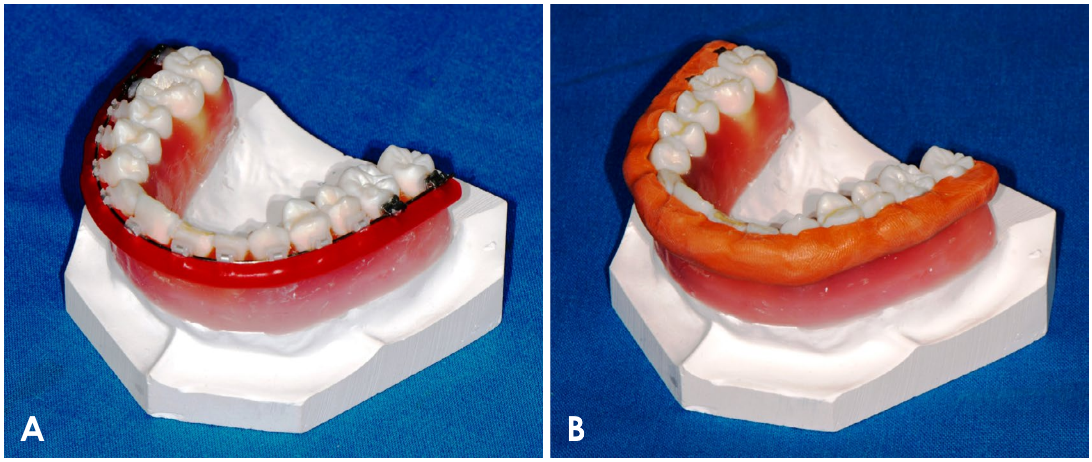

Fig. 3. Area of the typodont model with orthodontic brackets blocked out. Two types of block-out materials were used: A. Dental utility wax. B. Putty.

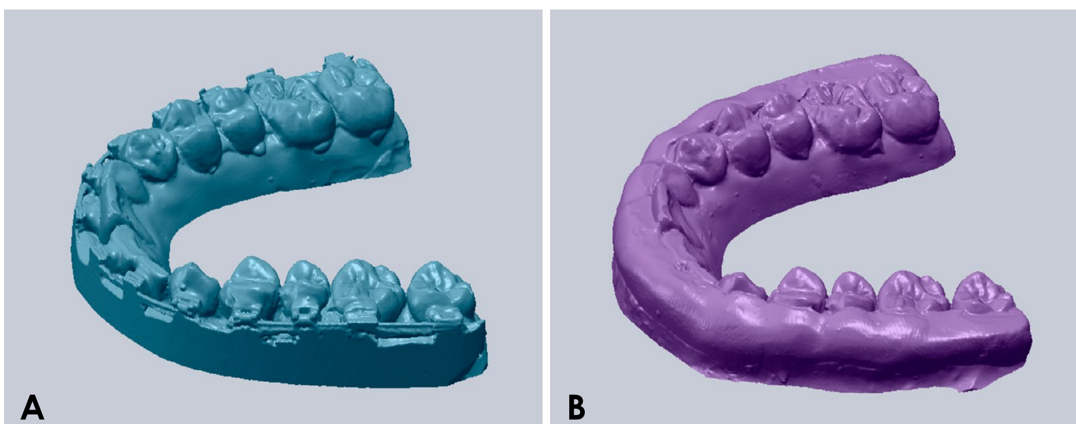

Fig. 4. Dental stone casts scanned using a 3-dimensional optical scanner. A. Digital cast model of the wax group. B. Digital cast model of the putty group.

Comparison of block-out methods used in acquisition of dental impressions

To mirror clinical practice when obtaining dental impressions, the area of the orthodontic brackets on the typodont model was blocked out to prevent tearing of the impression material. An experiment was conducted to compare 2 groups based on the type of material used to block out the brackets—wax or putty—during the impression-taking process.

More specifically, the 2 types of block-out materials used in this study were dental utility wax (Utility Wax for Technologic Dentistry; WAXCO) for the wax group (Fig. 3A) and putty (Express STD Putty; 3M ESPE Dental Products, St. Paul, MN, USA) for the putty group (Fig. 3B). Five dental cast models were created from plaster using dental impressions. These impressions were taken with alginate (Alginoplast; Heraeus, Hanau, Germany), and the dental casts were subsequently formed from dental stones (Mutsumi Chemical Industries, Yokkaichi, Japan) applied to the impressed material.

The dental casts were scanned in 3 dimensions using a 3D optical non-contact scanner (Rexcan DS2; Solutionix), from which stereolithography (STL) data were obtained. The dental cast models for the wax group and putty group are depicted in Figures 4A and 4B, respectively.

The typodont model was subjected to a CT scan using a Siemens Sensation 64 scanner (Siemens Medical Solutions, Malvern, PA, USA). The scan parameters included a 0.4375-mm pixel size, a 22.40-cm field of view, and a 0.4-mm slice thickness. The resulting data, in Digital Imaging and Communications in Medicine (DICOM) format, were reconstructed to create a 3D dental model, facilitating the

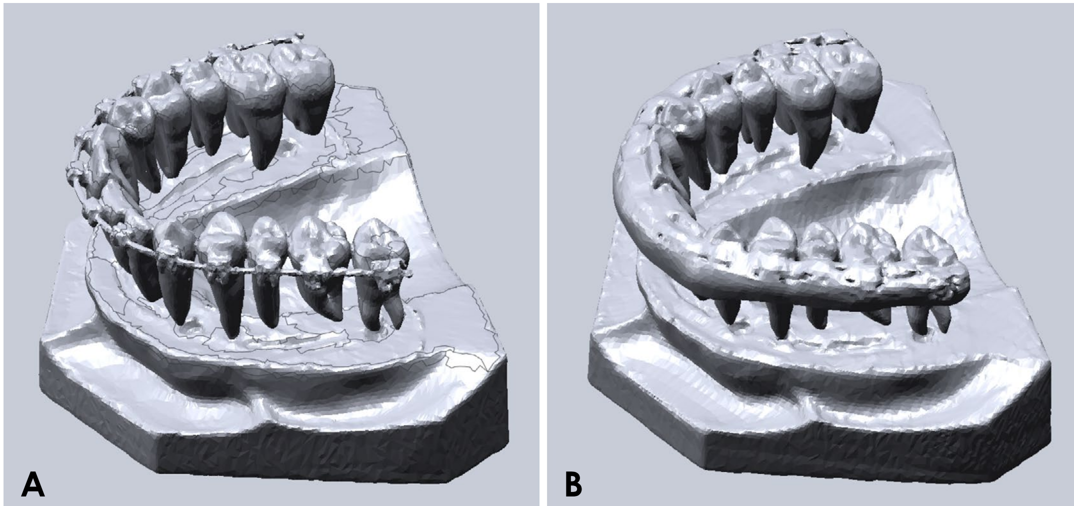

Fig. 5. Stereolithography (STL) files converted from Digital Imaging and Communications in Medicine (DICOM) format of the computed tomography (CT) scans of the blocked-out typodont model. A. DICOM CT files from the wax group were converted to STL format. B. DICOM CT files from the putty group were similarly converted.

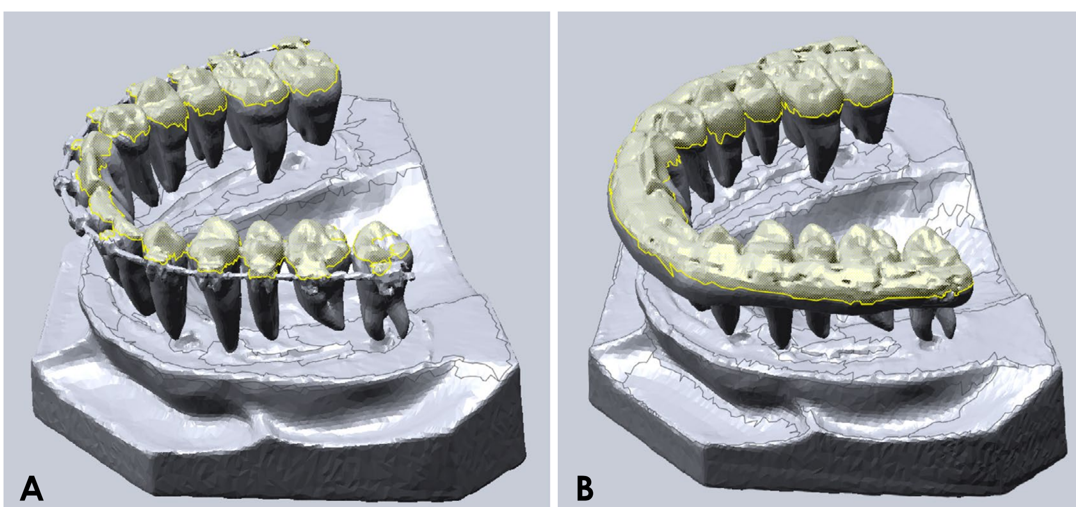

Fig. 6. Surface area (yellow mesh) utilized for surface-based registration to superimpose the digital data of the dental cast onto the computed tomography data of the typodont model. A. In the wax group, the occlusal surface area of the teeth was used. B. In the putty group, however, a broader area was utilized, encompassing both the occlusal surface of the teeth and the region where the putty blocked out the bracket.

integration of dental scan information. Each DICOM file was then imported into Mimics version 14.0 (Materialise, Leuven, Belgium), a program that converts DICOM files into STL files (Fig. 5). Using the program's functions, the DICOM data from the CT scans were converted into STL format.

In the wax group, the occlusal surface of the teeth served as the region for superimposing the digital dental cast data onto the CT data of the typodont model (Fig. 6A). In the putty group, a surface-based registration method was similarly employed to superimpose the digital dental cast data onto the CT data of the typodont model, which was blocked out with putty. However, the registration surface in this group was a wider area that included both the occlusal surface of the teeth and the region where the putty obscured the bracket (Fig. 6B).

The digital data of the dental cast model from the wax group were superimposed on the corresponding typodont CT data, also focusing exclusively on the occlusal surface area (Fig. 7A). For the putty group, the digital data of the dental cast model were overlaid on the corresponding typodont CT data, which had been blocked out with putty, using

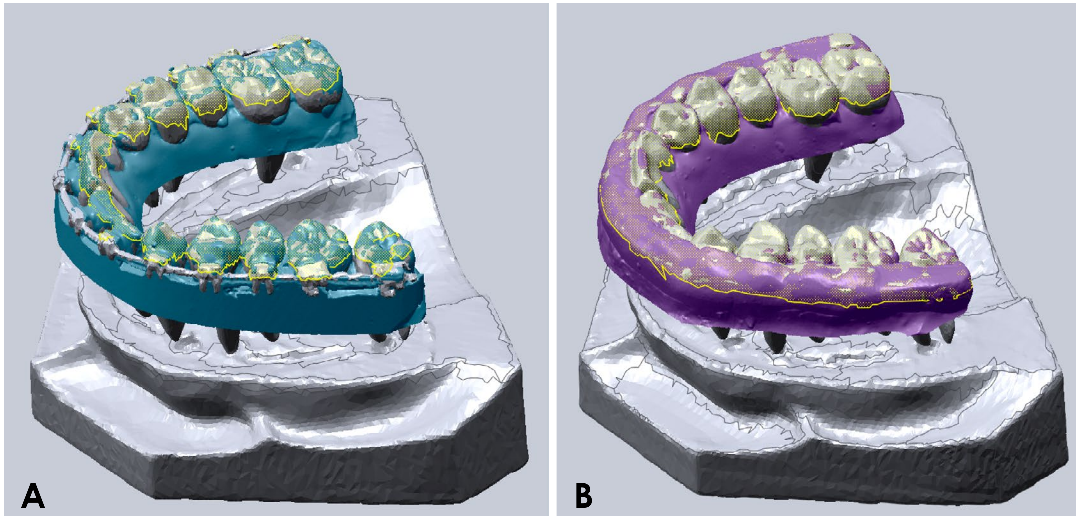

Fig. 7. A. Dental cast model data from the wax group are superimposed on the corresponding typodont computed tomography (CT) data using only the occlusal surface area. B. Digital data of the putty group's dental cast model are overlaid on the corresponding typodont CT data (obscured with putty) using surface-based registration that extends from the tooth occlusal surface to the putty area.

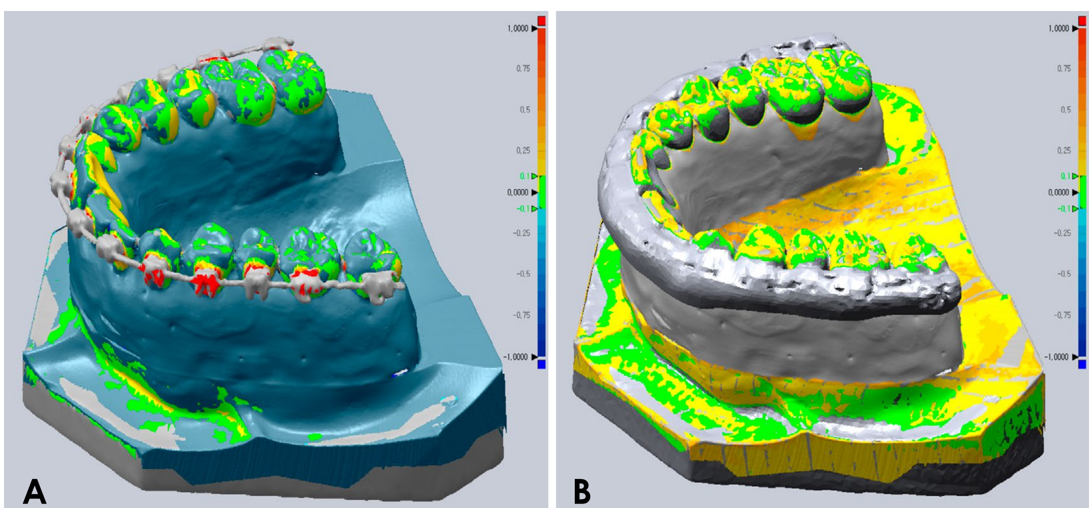

Fig. 8. Digital typodont model image data (Fig. 1) serve as reference data to compare the superimposition errors of dental cast images between 2 experimental groups: A. Wax and B. Putty. The error, which is color-coded in the figure, was quantified in the dental region spanning from the central incisor to the second molar in each group.

surface-based registration that extended from the tooth occlusal surface to the putty area (Fig. 7B).

Measurement of error

For error measurement, a 3D optical STL file representing the typodont model (Fig. 1) and an STL file converted from the DICOM files of each CT in the group were superimposed using the overall overlay function in Rapidform XOV2 (Inus Technology, Seoul, Korea). The resulting superimposed 3D optical scan data served as the reference to compare the error associated with the superimposed dental cast images between the 2 groups. This included both the occlusal surface and the blocked-out area present when the impression was taken. The same process was applied in instances where the occlusal surface was designated as the reference surface (Fig. 8).

When comparing the error in the superimposed digital dental images between the experimental conditions, a specialized inspection function of the Rapidform XOV2 software was employed. The error distance was measured and compared with the minimum error distance determined by the program. This error was quantified in the dental region spanning from the central incisor to the second molar for each experimental group. Four dental surfaces were assessed for each dental surface: palatal, buccal, mesio-occlusal (the area between the mesial marginal ridge and the mesial fossa in molars, and the mesial side of the incisal edge in incisors), and disto-occlusal (the area between the distal marginal ridge and the distal fossa in molars, and the distal side of the incisal edge in incisors). The absolute value of the error was taken as the measurement value.

The mean values between groups for the above measurements were compared using the *t*-test, while differences by measurement site within each experimental group were analyzed using analysis of variance. Statistical analyses were performed using SPSS version 23 (IBM Corp., Armonk, NY, USA), with *P*-values less than 0.05 considered to indicate statistical significance.

Results

When analyzing dental occlusal surface areas for substitution in CT images, fewer errors occurred when superimposition was performed using only the tooth occlusal surface area (Wax group), as opposed to including both the tooth area and the area containing putty impression material (Putty group) (Table 1). A significant difference in error was observed between the 2 experimental groups when the tooth coronal area was segmented into 4 surfaces: buccal, palatal, disto-occlusal, and mesio-occlusal.

When superimposition included the area blocked out with putty, the error ranged from 0.071 mm to 0.246 mm per measurement area. In contrast, when superimposition was limited to the occlusal surfaces, the error ranged from 0.05 mm to 0.052 mm ($P<0.001$), as shown in Table 1.

When each tooth was considered as the measurement region, a near-significant difference in the error of the superimposed areas was observed between groups (Table 2). When the superimposition included the area blocked out with putty, the error ranged from 0.1 mm to 0.2 mm per tooth. The smallest error on the palatal surface was observed in the putty group, with a mean error of 0.07 mm. In comparison, when only the occlusal surface area was used for superimposition, the error ranged from 0.03 mm to 0.05 mm ($P<0.001$).

Table 1. Errors in maxillary tooth coronal area due to the material used to block out the orthodontic bracket when taking the tooth impression (unit: mm)

	Wax (n = 70)	Putty (n = 70)	*P* value
Buccal surface	0.052 ± 0.041	0.141 ± 0.095	< 0.05
Palatal surface	0.046 ± 0.032	0.071 ± 0.041	< 0.05
Mesial occlusal surface	0.037 ± 0.023	0.246 ± 0.100	< 0.05
Distal occlusal surface	0.035 ± 0.024	0.204 ± 0.107	< 0.05

Table 2. Errors at each tooth due to the material used to block out the orthodontic bracket while taking the tooth impression (unit: mm)

	Wax (n = 40)	Putty (n = 40)	*P* value
Central incisor	0.050 ± 0.029	0.204 ± 0.101	< 0.05
Lateral incisor	0.045 ± 0.034	0.188 ± 0.112	< 0.05
Canine	0.049 ± 0.036	0.188 ± 0.101	< 0.05
First premolar	0.030 ± 0.022	0.202 ± 0.137	< 0.05
Second premolar	0.052 ± 0.037	0.165 ± 0.106	< 0.05
First molar	0.042 ± 0.027	0.111 ± 0.069	< 0.05
Second molar	0.032 ± 0.025	0.100 ± 0.095	< 0.05

Discussion

In clinical practice, dental models of patients undergoing orthognathic surgery or orthodontic treatment are created by taking impressions. To prevent tearing or deformation of the impression material, various intraoral devices are blocked out with materials such as wax. If a radiopaque block-out material is used, the area of its application may be included in the reference area when dental digital data are superimposed onto CT images. This study measured the error introduced when superimposing areas containing these materials, replicating the process used to obtain dental impressions in clinical settings.

Significant error was observed when putty was utilized as the radiopaque block-out material and surface-based superimposition included the area where the material was present. In short, the presence of the putty block-out material introduced errors on CT imaging, impacting the area of the orthodontic brackets attached to the labial surfaces of the teeth and positioned towards the lips. This error may present as an overall shift of position. Thus, discrepancies could likely be minimized if the block-out material enveloped the entire tooth, extending towards the lip and an opposing site, such as the palate or tongue. The findings of this study suggest that using conventional wax to block out orthodontic brackets—which is straightforward and widely accessible—is preferable for clinical practice.

To substitute the CT data of the dental region with more accurate digital dental imaging data, digital images of the teeth must be superimposed onto the CT images and replace them. This process requires the establishment of additional protocols for CT equipment development, image acquisition, and image superimposition.[4-6,10]

Methods for superimposing a digital dental image onto a CT image include surface-based registration and point-based registration. Reports suggest that using the occlusal surface area of the teeth for image superimposition results in fewer errors, offering dual benefits in utility and accuracy.[5,6,9,11]

Several methods are available for replacing the dental data obtained from CT scans.[6,8,12,13] Reports describe the superimposition of light scans or digital CT images of dental casts onto CT scans. Additionally, data from dental impressions and bite splints have been overlaid onto CT scans, and scanned impression data have been superimposed onto 3D photographic images.[5-8]

The methods for replacing the dental area in CT images with bite splints or impression materials eliminate the need for plaster dental models and employ noninvasive registration techniques alongside registration markers, facilitating template-based registration. However, these methods also have drawbacks, such as the requirement to produce impression material prior to CT imaging and the necessity for the patient to maintain a bite or hold the impression material during the CT scan, or, alternatively, to undergo additional scans.[5] Superimposing and replacing the dental area in a CT scan with digital data from a 3D light scan of a dental cast model presents the disadvantage of necessitating the creation of a dental cast model. Nonetheless, the direct oral light scan is straightforward to use and more convenient than scanning the impression material.[11]

If dental data are obtained through an intraoral scan, no change in facial soft tissue is produced when using an intraoral bite. Direct scanning of teeth within the oral cavity eliminates errors associated with the impression-taking process and the production of dental cast models. However, due to the nature of intraoral scanning, errors may arise from using a small camera to capture the scanning surfaces, which can be challenging when navigating the narrow confines or broad expanse of the dental arch.[14,15] Furthermore, because scan data often involve substantial overlap, more point data are located on the tooth surface, potentially yielding a representation that is thicker than the actual tooth. When creating a CAD/CAM surgical guide for orthognathic surgery, the defective area within the dental data must be minimal. Applying powder to the tooth surface can also increase the accuracy of intraoral scans.[16]

Although directly scanning teeth has advantages and disadvantages, in the context of orthognathic surgery, it is particularly important to utilize analog dental casts.[11,17] Planning and establishing dental occlusion digitally, using digital dental data, can be challenging. However, employing an analog dental cast model simplifies the process for orthodontists to plan, experiment with, and construct various prospective dental occlusions between the maxilla and mandible. Consequently, this study focused on investigating errors associated with using data from scans of analog dental casts, as opposed to data acquired by directly scanning teeth within the oral cavity.

When replacing the image of the dental area on CT with a more detailed digital image, digital data must be superimposed onto the CT. For successful marker-free, surface-based registration as employed in this study, the CT image and the dental digital image must be sufficiently similar. In the present study, the authors attempted to expand the surface area used for superimposition with putty and to determine the impact on superimposition error. The findings indicated that although the use of putty increased the reference surface area, the error was also larger. The primary cause of this increased error is likely that the expanded area extended only to the labial or buccal region.

Based on the study results, superimposing the CT image by using the occlusal surface area is more straightforward and is therefore the recommended method for clinical practice when utilizing digital data from dental cast scans. The acquisition of impressions and the creation of dental models with block-out material captured on CT is not advised, as the material introduces significant error and is cumbersome to handle. Nevertheless, other reports have described applying dental materials to dental prostheses and orthodontic devices to minimize artifacts in CT.[18,19] No such method was utilized in the present study. During the construction of a 3D image from a CT scan, the Hounsfield unit value was set to minimize artifacts from brackets and wires without compromising the quality of the experimental model's image. However, this method is not directly applicable to actual patients. The experimental model was scanned in air, whereas in patients, the oral cavity and face comprise both hard and soft tissues. Various methods of artifact reduction are being attempted for this complex environment.

Overall, further research on this subject is necessary. It is crucial to verify that materials, including block-out materials, do not alter facial soft tissue during CT scans, as this could introduce errors in facial soft tissue measurements. Additionally, ongoing investigation should explore more accurate and accessible methods to overcome the current limitations of imaging and superimposition, progressing toward using more precise digital imaging data of the dental area.[20-22]

Based on the present findings, the clinical recommendation is to use radiolucent wax to block out the orthodontic bracket when obtaining dental impressions. Furthermore, for the accurate superimposition of CT dental images with scanned digital data from a dental cast model, it is sufficient to perform surface-based registration using only dental occlusal surface data.

Conflicts of Interest: None

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