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Accurate registration of cone-beam computed tomography scans to 3-dimensional facial photographs

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Introduction: Registering a 3-dimensional (3D) facial surface scan to a cone-beam computed tomography (CBCT) scan has various advantages. One major advantage is to compensate for the inaccuracy of the CBCT surface data. However, when registering CBCT and 3D facial scans, changes in facial expression, spatial soft-tissue changes, and differences in the patient's positioning can decrease the accuracy of the registration. In this study, we introduce a new 3D facial scanner that is combined with a CBCT apparatus. Our goal was to evaluate the registration accuracy of CBCT and 3D facial scans, which were taken with the shortest possible time between them. **Methods:** The experiment was performed with 4 subjects. Each patient was instructed to hold as still as possible while the CBCT scan was taken, followed immediately by the 3D facial surface scan. The images were automatically registered with software. The accuracy was measured by determining the degree of agreement between the soft-tissue surfaces of the CBCT and the 3D facial images. **Results:** The average surface discrepancy between the CBCT facial surface and 3D facial surface was 0.60 mm (SD, 0.12 mm). Registration accuracy was also visually verified by toggling between the images of the CBCT and 3D facial surface scans while rotating the registered images. **Conclusions:** Registration of consecutively taken CBCT and 3D facial images resulted in reliable accuracy. (Am J Orthod Dentofacial Orthop 2014;145:256-64)

Accurate diagnosis is the key to treatment planning and a successful treatment outcome. Many clinicians evaluate facial contours, especially the profile, when setting goals for treatment. From the perspectives of function, stability, and esthetics, the orthodontist must plan treatment within the patient's limits of soft-tissue adaptation and contours.[1] Holdaway[2] emphasized that the best possible soft-tissue profile should be established first, followed by tooth movement that will best develop the patient's ideal profile. Park and Burstone[3] challenged the idea that optimal occlusion and strict adherence to hard-tissue cephalometric standards lead to good facial form. They concluded that using a cephalometric standard based on hard tissues alone would not produce a given profile type, and that achieving good facial esthetics requires consideration of the overlying soft-tissues in orthodontic treatment planning.

It is essential to analyze accurate imaging data that represent the "anatomic truth" of the patient's real anatomy.[4] Diagnostic imaging has been a part of orthodontic patient records for decades. Traditionally these images are 2-dimensional (2D) cephalometric images and tracings, panoramic images, and 2D photographs. Three-dimensional (3D) data were confined to study models. One standard diagnostic tool in orthognathic surgery and preoperative orthodontic treatment is the 2D facial photograph. These diagnostic elements have serious limitations in a thorough evaluation of the 3D structures of a patient's face.[5] Over the past few years, cone-beam

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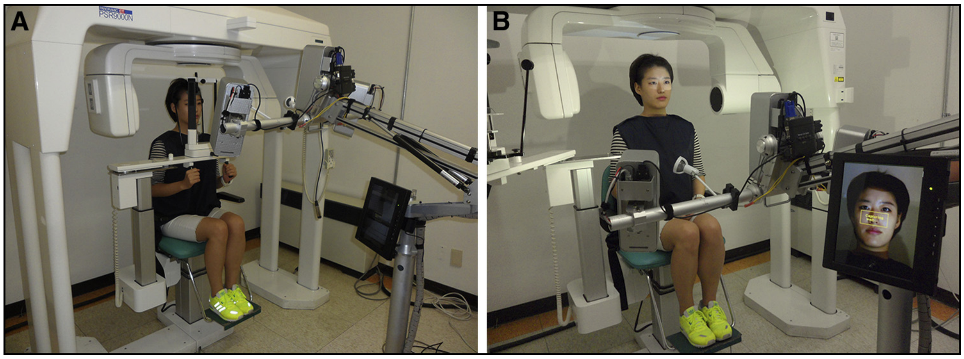

Fig 1. A, Scanning of CBCT followed immediately by **B,** the 3D facial photograph. The patient maintained the same posture during both scans.

computed tomography (CBCT) has been used to aid in diagnosis and treatment planning. However, soft-tissue images taken from CBCT data are not very accurate and do not capture the true color and texture of the skin.

Recently, studies have been conducted to merge the CBCT images to the 3D facial surface scans.[6] Schendel and Lane[7] described the advantages of anatomically registering 3D facial surface images to CBCT data. They proposed that surface images can correct CBCT surface artifacts caused by several situations. Patient movement is more likely when the patient is upright rather than supine (ie, swallowing, breathing, head movement, and so on). The time interval to take the CBCT scans can vary among machines from 5 to 70 seconds, and a longer interval allows more movement. CBCT device stabilization aids (chin rest, forehead restraint) can distort the surface anatomy recorded in the CBCT image. Surface images also can supplement any missing anatomic data (nose, chin, and so on) when taking a CBCT scan of an upright patient. Finally, a surface scan provides a more accurate representation of the draping soft tissues that reflect the patient's natural head position.

In a typical 2D cephalograph, hard-tissue and soft-tissue images are represented in 1 image. Therefore, there is no margin of error in the correlation between them. However, errors can occur when registering a CBCT image with a 3D facial photo or surface scan. Any errors in the integration of the 3D soft tissues and skull models could increase the cumulative errors of the prediction planning method and could transfer to errors in orthodontic or surgery planning.[8] Reducing errors during registration of the CBCT and 3D surface scans is beneficial for a correct diagnosis. In this preliminary study, we aimed to introduce a new 3D facial scanner combined with a CBCT apparatus and to evaluate the registration accuracy of CBCT and 3D facial surface scans that were taken with the least possible time between scans.

MATERIAL AND METHODS

CBCT and 3D facial surface scans are usually taken in different locations and at different times before being merged. Ayoub et al[9] reported that registration errors were within $\pm$1.5 mm when CBCT and 3D facial surface scans were taken separately. These errors were attributed to minor changes in facial expression, spatial soft-tissue changes, and differences in the patient's positioning during capture. In their study, facial scans were taken in the sitting position, and the CBCT scan was taken in the supine position. According to Naudi et al,[8] the level of superimposition accuracy from the delayed captures was between 0.3 and 0.9 mm, whereas the superimposition accuracy for the simultaneously captured images was 0.4 mm or less. In our study, a 3D facial scan was taken immediately after a CBCT scan in the same room and with the patient in the same posture. These scans were used to evaluate registration accuracy. A 3D optic scanning system (3D Neo; Morpheus, Gyoung-gi, Korea) was used for the 3D facial surface scans (Fig 1). This system uses white light from light-emitting diodes because it is safe to eyes. It acquires a 3D surface image by projecting structured patterns on the subject and analyzing the deformation of the patterns. When patterned light is projected on an object, the sensor acquires on-and-off light information. Scanning is sensitive to surface material properties such as strongly reflective or translucent objects compared with noncontact and passive methods.[10] This scanning method was less restricted because of its compact size (height, 200 cm; depth, 80 cm; width, 90 cm) and the transmission of the data by Wi-Fi.

The Morpheus 3D software automatically registers the extracted skin surface of the CBCT image and the surface of the 3D facial scan to obtain optimal registration parameters based on the rigid transformation including the x-axis, y-axis, and z-axis translations

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